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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2261

WIND-TUNNEL INVESTIGATION OF A NUMBER OF TOTAL-PRESSURE TUBES AT HIGH ANGLES OF ATTACK

SUPERSONIC SPEEDS

By William Gracey, Donald E. Coletti, and
Walter R. Russell

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A wind-tunnel investigation has been conducted to determine the effect of inclination of the air stream on the measured pressures of 20 total-pressure tubes through an angle of attack of -15° to 45° at Mach numbers 1.62, 1.94, and 2.40. Results obtained with these same tubes at subsonic speeds have been previously reported in NACA RM L50G19.

The results of the investigation have indicated that, in general, the range of angle of attack over which the tubes remained insensitive to inclination was appreciably greater at supersonic speeds than at subsonic speeds. The increase in range of insensitivity for most of the cylindrical tubes was from about 4° to 6°; whereas the increase for conical- and ogival-nose sections was from about 4° to 10°. The only tube which showed a decrease in performance at supersonic speeds was a shielded total-pressure tube (Kiel type), which was insensitive (to within 1 percent of the impact pressure) over an angle-of-attack range of $\pm 41.5^\circ$ at subsonic speeds but only $\pm 37^\circ$ at a Mach number of 1.94. The range of insensitivity of this tube, however, was still the greatest of any of the tubes tested, both at subsonic and at supersonic speeds.

The present tests also showed that the effect of the various design variables was the same at supersonic speeds as at subsonic speeds. The performance of cylindrical tubes, for example, was superior to that of tubes having conical- and ogival-nose shapes. Sharp leading edges and impact openings which were large with respect to the diameter of the tube were also shown to increase the performance of the tube. Conical chambers were shown to have better misalinement characteristics than cylindrical chambers, and chambers having a 15° bevel angle were found to be superior to larger internal bevels. A leading-edge profile having a slant angle of 10° was found to have a beneficial effect in shifting the calibrations of a cylindrical tube with a large impact opening so that the tube remained insensitive to higher positive angles of attack.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting a wind-tunnel investigation to determine the effect of inclination of the air stream on the measured pressures of various types of total-pressure tubes at both subsonic and supersonic speeds. The purpose of this investigation is to establish the optimum configuration of a fixed total-pressure tube for use at high angles of attack.

The need for insensitive fixed tubes has arisen because of the development of airplanes capable of reaching high angles of attack at supersonic speeds and because of the fact that conventional total-pressure tubes, both fixed and swiveling, are unsatisfactory for the measurement of total pressure under these conditions. The conventional fixed tube is unsatisfactory because of large errors due to inclination of the tube to the air stream; whereas swiveling tubes (that is, fixed tubes having a pivot-and-vane arrangement for alining the tube with the air stream) are considered undesirable because of the possibility of structural failure at high speeds.

The results of tests of 39 total-pressure tubes in the subsonic-speed range have been previously reported in reference 1. The present paper presents the results of similar tests of 20 of these tubes at supersonic speeds. As was done in reference 1, the results of the present tests are being presented without detailed analysis.

SYMBOLS

d	diameter of impact opening of total-pressure tube
D	body diameter of total-pressure tube
H'	stagnation pressure measured by a total-pressure tube at $\alpha = 0^\circ$
H''	stagnation pressure measured by a total-pressure tube at $\alpha \neq 0^\circ$
ΔH	total-pressure error $(H'' - H')$
p_s	stream static pressure in vicinity of total-pressure entry of total-pressure tubes
q_c'	indicated impact pressure $(H' - p_s)$

M stream Mach number in vicinity of total-pressure entry of total-pressure tubes

α angle of attack of total-pressure tube, degrees

APPARATUS AND TESTS

The 20 total-pressure-tube configurations which were tested during this series of tests are shown in figure 1. Diagrams of each of the tubes are given in the calibration charts at the end of this paper. The various tubes have been classified, as was done in reference 1, according to their external shape into five groups: cylindrical (series A), 15° conical (series B), 30° conical (series C), 45° conical (series D), and ogival (series E). The designations of the tubes are also the same as those used in reference 1. Tubes A-2 and A-3 shown in figure 1 were the same except for the thickness of the wall at the forward section of the tube.

The length of the tubes shown in figure 1 was $4\frac{7}{8}$ inches, this length being the maximum length which could be used with the swivel apparatus, test section, and angular-deflection range employed for tests of these tubes. With the exception of tube A-13, the body diameter of each of the tubes was 1 inch. The body diameter of tube A-13 was reduced to 3/4 inch in order that the over-all length could be kept within $4\frac{7}{8}$ inches and the relative proportions of the Kiel tube design given in reference 2 could be retained. Upon completion of the tests of the full-scale tubes, additional tests were conducted on $\frac{1}{4}$-inch-diameter models of five of the tubes in order that the effects of tunnel interference or choking might be determined.

The tests were conducted in the Langley 9-inch supersonic tunnel. The apparatus used for changing the angle of attack of the tubes was a specially designed U-tube mechanism attached to the side of the tunnel wall (figs. 2 and 3). This tube support was designed with the axis of rotation of the swivel arm in line with the leading edge of the total-pressure tube. With this arrangement, the total-pressure entry remained at the same point in the air stream for all angles of attack. The approximate inclination of the tube to the air stream was set by means of a control arm and angular scale mounted on the outside of the tunnel wall (figs. 3 and 4). The exact inclination was measured by means of a cathetometer located outside the tunnel.

Each of the 20 full-scale tubes was tested at $M = 1.62$. In addition, tube A-13 was tested at $M = 1.94$ and $M = 2.40$ and tubes A-6

and A-7 at $M = 2.40$. Of the five small-scale tubes, four were tested at $M = 1.62$ and one at $M = 1.94$. For each of these tests the tubes were rotated through an angular range of -15° to 45° in increments of about $2\frac{1}{2}^\circ$ and 5°. Because of the limited size of the tunnel test section, rotation of the tubes to angles of 45° in both directions as was done for the subsonic tests of reference 1 was impossible. Data for large negative angles, however, are of academic interest only and were obtained in the subsonic tests simply for the purpose of checking the symmetry of the calibration about zero angle of attack.

The total-pressure errors of each of the tubes were determined as the difference between the pressure registered by the tube at a given angle of attack and the pressure registered by the same tube at zero angle of attack. The Mach numbers at which the tests were conducted were determined on the basis of previous surveys of the stagnation and static pressures across that part of the test section where the test tubes were located. As the pressures in the test section are a function of the stagnation pressure in the settling chamber ahead of the test section, the relation between the pressures in the two sections of the tunnel was determined during the pressure-survey tests and was used during the present tests to establish the stream pressures for each test run.

The accuracy of the stream Mach number at any one point in the stream was found from the pressure-survey tests to be within the reading accuracy of the measurements (± 0.005 M), and the variation of Mach number from point to point in the region occupied by the tubes was of the same order. The humidity in the tunnel was maintained at a value where errors due to condensation losses were negligible with the result that all of the test tubes indicated the correct stagnation pressure behind a normal shock (at $\alpha = 0^\circ$) within the accuracy of the stream Mach number. The accuracy of the incremental total-pressure error $\Delta H/q_c'$ was estimated to be within ± 0.002 and the accuracy of the angle-of-attack measurements to be within $\pm 0.1^\circ$. The Reynolds numbers at which the tests were conducted were 3.62×10^5 per inch at $M = 1.62$, 3.12×10^5 per inch at $M = 1.94$, and 2.51×10^5 per inch at $M = 2.40$.

RESULTS AND DISCUSSION

The variation of total-pressure error with angle of attack of the 20 total-pressure tubes is presented in figures 5 to 24. The total-pressure error ΔH is defined by the relation $H'' - H'$, where H'' is the pressure registered by the tube at a given angle of attack and H' is the pressure registered by the same tube at zero angle of attack. These total-pressure errors are presented as fractions of the indicated

impact pressure q_c'. The quantity q_c' in turn is defined by the relation $H' - p_s$, where p_s is the stream static pressure in the vicinity of the total-pressure entry of the tube.

The calibrations of the various total-pressure tubes are compared to show the effects of variations in both internal and external geometry on the sensitivity of the tube to misalinement. The basis for these comparisons is the range of angle of attack over which the tube remains insensitive to inclination to within 1 percent q_c' (herein called the range of insensitivity). The range of insensitivity of each of the tubes as determined from the present tests is summarized in table I together with corresponding subsonic values from reference 1. The total range of insensitivity given in this table for symmetrical tubes is twice the range determined at positive angles, since the angular-deflection range was, in most cases, insufficient to define the range of insensitivity at negative angles. This assumption is justified as the subsonic tests showed that the ranges of insensitivity at positive and negative angles of attack were equal for symmetrical tubes.

During the course of this investigation, some of the full-scale tubes vibrated rather violently at angles of attack above a certain value (usually about 35°) and, under these conditions, the variation of total-pressure error with angle of attack became nonuniform or erratic. Repeat tests with shadowgraph observations indicated that these irregularities were associated with an upstream movement of the normal shock wave of the tunnel to a point in the vicinity of the total-pressure tube. In addition, the proximity of the tunnel shock to the nose of the tube was shown to vary, the variation depending on the angle of attack, size, and shape of the tube. Subsequent tests of a representative group of small-scale tubes showed no evidence of tunnel interference and, as is shown subsequently, the results of the tests of large-scale tubes showed good agreement with the data of the smaller tubes for angles of attack up to 35°. The calibrations for all of the full-scale tubes have, therefore, been arbitrarily terminated at $\alpha = 35°$, except in two cases (tubes A-6 and A-13) where the test data are presented for slightly higher values for comparison with the small-tube results.

Cylindrical tubes, series A.- The variation of total-pressure error with angle of attack of nine cylindrical tubes is presented in figures 5 to 13. The design of these tubes was varied in such a manner that the effects of size of the impact opening, shape of the internal chamber, slant profile, internal bevel, and shielding (combined with venting) might be studied.

The effect of impact-opening size (that is, the ratio of the impact-opening diameter d to the tube diameter D) may be determined from figures 5 to 7. Comparison of figures 5 and 6 shows that increasing the

size of the impact opening has a beneficial effect on the performance of the tube; the range of insensitivity of tube A-2 $\left(\frac{d}{D} = 0.98\right)$ is ±29°, whereas that of tube A-1 $\left(\frac{d}{D} = 0.125\right)$ is only ±11°. Figures 6 and 7(a) show that the wall thickness may be increased from 1 to 2 percent of the tube diameter with no apparent decrease in the range of insensitivity. The results of these tests on impact-opening size agree essentially with those obtained at subsonic speeds.

The effect of variations in the shape of the internal chamber may be seen from a comparison of the calibrations of tubes A-4 and A-8 (figs. 8 and 11). These tubes had leading edges of the same shape (both had 20° internal bevels) but were different in that the chamber of the tube A-4 was cylindrical whereas that for tube A-8 was conical. The calibrations in figures 8 and 11 indicate that the effect of changing the shape of the internal chamber from cylindrical to conical is to increase the range of insensitivity of the tube and that the magnitude of this increase is 4°.

The effect of changing the leading-edge profile of a cylindrical tube from square to a 10° slant is shown in figures 6 and 9(a). Comparison of these figures shows that the range of insensitivity of the tube with the slant profile extends to 38°, whereas the range for the tube with the square profile is ±29°. As was shown in the subsonic tests of reference 1, the slant profile has the effect of simply shifting the calibration of the square-end tube along the angle-of-attack scale without decreasing the over-all range of insensitivity. Although the negative range was not determined in the present tests, from the data presented the calibration appears to have been shifted by 9°; this shift corresponds almost exactly to the shift at subsonic speeds. On the basis of these results, the negative range is estimated to be -20°. It may be noted that the range of insensitivity of this tube at positive angles is comparable to that of the shielded tube which is discussed in a subsequent paragraph.

The effect of varying the internal bevel of a cylindrical tube is given in figures 10(a), 11, and 12. As indicated by these figures, the ranges of insensitivity of tubes having internal bevels of 15°, 20°, and 25° are 32°, 31.5°, and 30°, respectively. These results are in general agreement with the subsonic data in showing that the range of insensitivity increases with decreasing bevel angle.

The characteristics of a straight-walled tube having an internal bevel of about 15° and an annular passage for venting the air to the rear of the total-pressure orifice (shielded total-pressure tube) are given in figure 13(a). The configuration of this tube is based on a design for a spindle-mounted Kiel tube given in reference 2. In the

present design the spindle has been eliminated (because it caused the tube to vibrate at high speeds) and the rear part of the tube was adapted for end mounting on a horizontal boom. In addition, the internal chamber has been vented along the side walls of the tube instead of directly to the rear as in the case of the spindle-mounted tube. For this particular design the vents have been located about 4 tube diameters to the rear of the nose and the combined area of the vents has been made equal to 1.5 times the frontal area of the tube. As indicated by figure 13(a) this tube remains insensitive over an angle-of-attack range of 38.5° at M = 1.62. The normal shock of the tunnel, however, was ahead of the vent orifices at the higher angles of attack so that the figure for the range of insensitivity as determined by these tests is of doubtful accuracy. As will be shown in the discussion of the tests of smaller tubes, the more nearly correct value for this tube configuration is 37°

The effect of Mach number on the characteristics of cylindrical tubes in the supersonic speed range is shown in figures 9(b), 10(b), and 13(b). Figures 9(b) and 10(b) show that the sensitivity of the unshielded tubes A-6 and A-7 is essentially unaffected by a change in Mach number from 1.62 to 2.40. Figure 13(b), on the other hand, would tend to indicate that the range of insensitivity of shielded tube A-13 is the same at M = 1.62 and 1.94 but considerably less at M = 2.40. As noted previously, however, the data for tube A-13 at M = 1.62 are considered unreliable at the higher angles because of the passage of the tunnel shock across the vent orifices of the tube. As these same effects were noted during the tests at M = 1.94 and M = 2.40, the data at these Mach numbers are also unreliable so that the results of these tests cannot be considered an accurate indication of the effect of Mach number on this tube for angles above about 30°. The calibrations of all three of these tubes at M = 2.40 show an apparent rise to positive value of $\Delta H/q_c'$ at angles of attack below 35°. These discrepancies are thought to result from deviations in stream total pressure at the total-pressure tube which do not appear as corresponding variations in the settling-chamber pressure. As these variations in $\Delta H/q_c'$ were in all cases within 1 percent q_c', however, the range of insensitivity of the tubes as defined by the 1-percent deviation at higher angles remains unaffected. On the basis of these results, it may be concluded that the characteristics of unshielded cylindrical tubes are not appreciably affected by variations in Mach number in the supersonic speed range.

The performance of most of these tubes at subsonic speeds, on the other hand, is considerably different from that at supersonic speeds. Examination of the values in table I, for example, shows that, with the exception of tubes A-1 and A-13, the range of insensitivity of cylindrical tubes at supersonic speeds is greater by about 4° to 6°. The range of insensitivity of tube A-1 is the same in both speed ranges;

whereas that for tube A-13, as indicated by the small-tube value, is about 4° smaller at supersonic speeds. These results show that except for unusual configurations such as the shielded tube, the presence of a shock wave ahead of a cylindrical tube is generally effective in increasing the insensitivity of the tube to inclination. Despite the loss in performance of tube A-13 at supersonic speeds, the range of insensitivity was still the greatest of any of the tubes tested, at both subsonic and supersonic speeds.

The results of tests of $\frac{1}{4}$-scale models of tubes A-3, A-6, and A-7 at $M = 1.62$ and a $\frac{1}{3}$-scale model of tube A-13 at $M = 1.94$ are given in figures 7(b), 9(c), 10(c), and 13(c) together with corresponding calibrations of the full-scale tubes. As indicated by these figures the ranges of insensitivity of the full-scale versions of tubes A-3, A-6, and A-7 agree with those of the smaller tubes to within 1°. The calibrations of the full-scale models of these tubes, therefore, appear to be essentially correct despite the fact that the normal shock of the tunnel was just rearward of the nose of the tubes at the higher angles. The data for the full-scale tube A-13, however, are considered unreliable (even though the ranges of insensitivity of the large and small tubes agree to within 1.5°) for, in this case, the large tube came under the influence of the tunnel shock when the shock had reached the vent orifices In the tests of the small-scale model of this tube the tunnel shock remained downstream of the tube at all times. The range of insensitivity as defined by these tests (37°) is, therefore, considered the more reliable value for this tube configuration.

15° conical-nose tubes, series B.- Calibrations at $M = 1.62$ of six total-pressure tubes having a 15° conical-nose section are presented in figures 14 to 19. The design variables which were investigated with this external shape were sharpness of total-pressure entry and internal bevel.

Sharpening the total-pressure entry is shown by figures 14 to 16 to be quite effective in increasing the range of insensitivity of the tube. The range of insensitivity of the sharp entry, for example, is 12° greater than that of the tube having 0.05-inch wall thickness at the impact opening. A further increase in wall thickness to 0.10 inch, however, results in an additional decrease in range of insensitivity of only 3°. These results on the effect of leading-edge sharpness are in general agreement with the subsonic data.

The characteristics of 15° conical-nose tubes having internal bevels of 15°, 20°, and 25° are given in figures 17 to 19. As indicated by these figures, the ranges of insensitivity are 29.5°, 28.5°, and 27.5°, respectively. Although the difference in tube sensitivity is comparatively

small, some increase in tube performance appears to be gained by the use of the smaller bevel angles.

The effect of Mach number on the sensitivity of these tubes may be seen from table I. Comparison of the results of the subsonic and supersonic calibrations will show that the range of insensitivity of the tubes at supersonic speeds is from 30 to 50 percent greater than at subsonic speeds. The range of insensitivity of the sharp-nose tube and the three internal-bevel tubes, for example, was increased by an average of 9°; whereas the range of insensitivity of the two blunt-nose tubes was increased about 4°.

The calibration of a $\frac{1}{4}$-scale model of tube B-4 at $M = 1.62$ is compared with that of the full-scale tube in figure 17(b). As in the case of the cylindrical tubes, the ranges of insensitivity of the large and small tubes agree to within 1°.

30° conical-nose tubes, series C.- The misalinement characteristics of total-pressure tubes having a 30° conical-nose section and internal bevel of 15°, 20°, and 25° are given in figures 20 to 22 for a Mach number of 1.62. Examination of these figures shows that the range of insensitivity decreases from 28.5° to 28 to 27.5° as the bevel angle increases from 15° to 20° to 25°. The effect of the bevel angle is, therefore, the same as that for the 15° conical-nose tubes except that the difference in tube sensitivity for the same difference in bevel angle is even smaller.

The effect of Mach number on the performance of these tubes (table I) is the same as that for the 15° conical-nose tubes having internal bevel entries; that is, the range of insensitivity is greater at supersonic speeds and the increase over the subsonic values is of the same order (8° to 10°).

45° conical-nose tubes, series D.- The calibrations of a 45° conical-nose tube having a 20° internal bevel are given in figure 23 for Mach number 1.62. As indicated by this figure, the range of insensitivity at positive angles of attack is 24.5° which is 9.5° greater than the range at subsonic speeds.

Ogival-nose tubes, series E.- The misalinement characteristics at $M = 1.62$ of a total-pressure tube having an ogival-nose section and a 20° internal bevel are presented in figure 24. The range of insensitivity of this tube is 28° which is 9.5° higher than that for subsonic conditions.

External shape, series A, B, C, D, and E.- The variation of tube sensitivity with external shape may be determined from a comparison of the calibrations of tubes having similar total-pressure entries in each

of the five series. Such a comparison may be made by reference to the calibrations of tubes A-8, B-5, C-7, D-5, and E-5 at a Mach number of 1.62 (figs. 11, 18, 21, 23, and 24). The ranges of insensitivity of these tubes are ±32°, ±28.5°, ±28°, ±24.5°, and ±28°, respectively. As indicated by these values, the misalinement characteristics of cylindrical tubes are superior to those of the other four shapes. Of the three conical-nose shapes, the smallest cone angle (15°) shows the least sensitivity to inclination. The range of insensitivity of the ogival-nose section is about the same as that for the 15° and 30° conical-nose tubes. The effect of external shape, like that of the other design variables discussed previously, is the same in both the subsonic and supersonic speed ranges.

CONCLUDING REMARKS

A wind-tunnel investigation of 20 total-pressure-tube configurations has been conducted over an angle-of-attack range of -15° to 45° at Mach numbers of 1.62, 1.94, and 2.40. The results have indicated that, in general, the range of angle of attack over which the tubes remained insensitive to inclination was appreciably greater at supersonic speeds than at subsonic speeds. The increase in range of insensitivity for most of the cylindrical tubes was from about 4° to 6°; whereas the increase for conical- and ogival-nose sections was about 4° to 10°. The only tube which showed a decrease in performance at supersonic speeds was a shielded total-pressure tube (Kiel type), which was insensitive (to within 1 percent of the total impact pressure) over an angle-of-attack range of 41.5° at subsonic speeds but only 37° at a Mach number of 1.94. The range of insensitivity of this tube, however, was still the greatest of any of the tubes tested, both at subsonic and at supersonic speeds.

A comparison of the results of the present investigation with those of the subsonic investigation also showed that the effect of the various design variables was the same at supersonic speeds as at subsonic speeds. The performance of cylindrical tubes, for example, was superior to that of tubes having conical- and ogival-nose shapes. Sharp leading edges and impact openings which were large with respect to the diameter of the tube were also shown to increase the performance of the tube. Conical chambers were shown to have better misalinement characteristics than cylindrical chambers, and chambers having a 15° bevel angle were found to be superior to larger internal bevels. A leading-edge profile having

a slant angle of 10° was found to have a beneficial effect in shifting the calibrations of a cylindrical tube with a large impact opening so that the tube remained insensitive to higher positive angles of attack.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., October 19, 1950

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1. Gracey, William, Letko, William, and Russell, Walter R.: Wind-Tunnel Investigation of a Number of Total-Pressure Tubes at High Angles of Attack. Subsonic Speeds. NACA RM L50G19, 1950.

2. Kiel, G.: Total-Head Meter with Small Sensitivity to Yaw. NACA TM 775, 1935.

TABLE I.- ANGULAR RANGE OVER WHICH TOTAL-PRESSURE TUBES REMAIN INSENSITIVE TO INCLINATION TO WITHIN 1 PERCENT q_c

Tube	Figure	External shape	Internal shape	Total-pressure entry	Range of insensitivity, deg					
					Full-scale tubes				Small-scale tubes	
					Subsonic (a)	M = 1.62	M = 1.94	M = 2.40	M = 1.62	M = 1.94
A-1	5	Cylindrical		$\frac{d}{D}$ = 0.125, blunt	±11	±11	----	----------	----------	---
A-2	6	----do-----	Cylindrical chamber	$\frac{d}{D}$ = 0.98, blunt	±23	±29	----	----------	----------	---
A-3	7	----do-----	Cylindrical chamber	$\frac{d}{D}$ = 0.96, blunt	±23	±29	----	----------	±28	---
A-4	8	----do-----	Cylindrical chamber	$\frac{d}{D}$ = 0.92, 20° internal bevel	±23	±27.5	----	----------	----------	---
A-6	9	----do-----	Cylindrical chamber	$\frac{d}{D}$ = 0.98, blunt, 10° profile	-13, +32	[b]-20, +38	----	[b]-19, +39	[b]-20, +38	---
A-7	10	----do-----	15° internal bevel	Sharp	±27.5	±32	----	±32.5	±31	---
A-8	11	----do-----	20° internal bevel	Sharp	±25.5	±31.5	----	----------	----------	---
A-9	12	----do-----	25° internal bevel	Sharp	±23.5	±30	----	----------	----------	---
A-13	13	----do-----	Shielded and vented	Sharp	±41.5	[c]±38.5	[c]±38	[c]±32	----------	±37
B-1	14	15° cone		Sharp	±21	±29	----	----------	----------	---
B-2	15	----do-----		Blunt, 0.05-inch wall	±13	±17	----	----------	----------	---
B-3	16	----do-----		Blunt, 0.10-inch wall	±10.5	±14	----	----------	----------	---
B-4	17	----do-----	15° internal bevel	Sharp	±21	±29.5	----	----------	±28.5	---
B-5	18	----do-----	20° internal bevel	Sharp	±19	±28.5	----	----------	----------	---
B-6	19	----do-----	25° internal bevel	Sharp	±18	±27.5	----	----------	----------	---
C-6	20	30° cone	15° internal bevel	Sharp	±20.5	±28.5	----	----------	----------	---
C-7	21	----do-----	20° internal bevel	Sharp	±18	±28	----	----------	----------	---
C-8	22	----do-----	25° internal bevel	Sharp	±17.5	±27.5	----	----------	----------	---
D-5	23	45° cone	20° internal bevel	Sharp	±15	±24.5	----	----------	----------	---
E-5	24	Ogival	20° internal bevel	Sharp	±18.5	±28	----	----------	----------	---

[a]From reference 1.
[b]Estimated.
[c]Accuracy uncertain.

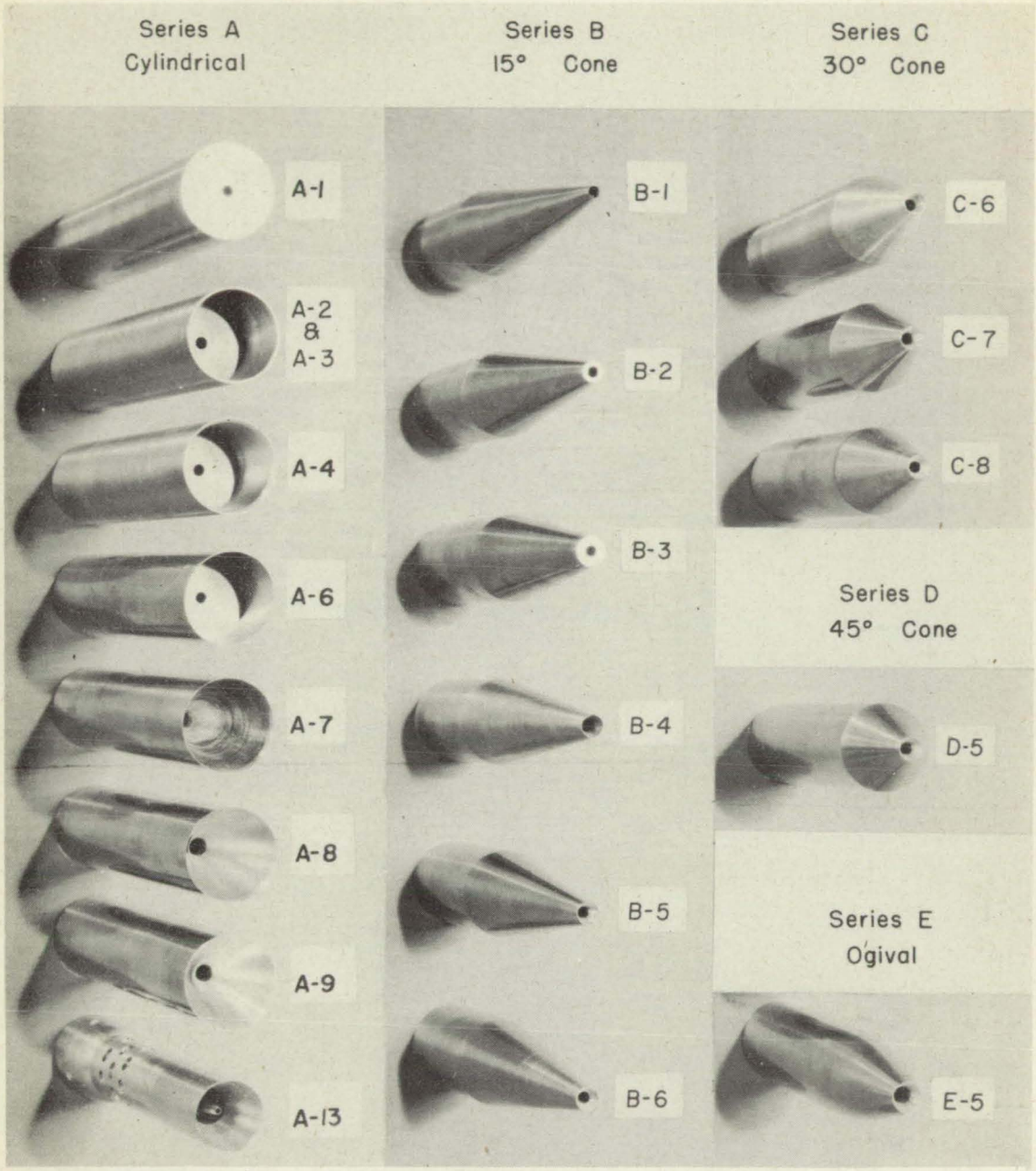

Figure 1.- Total-pressure tubes.

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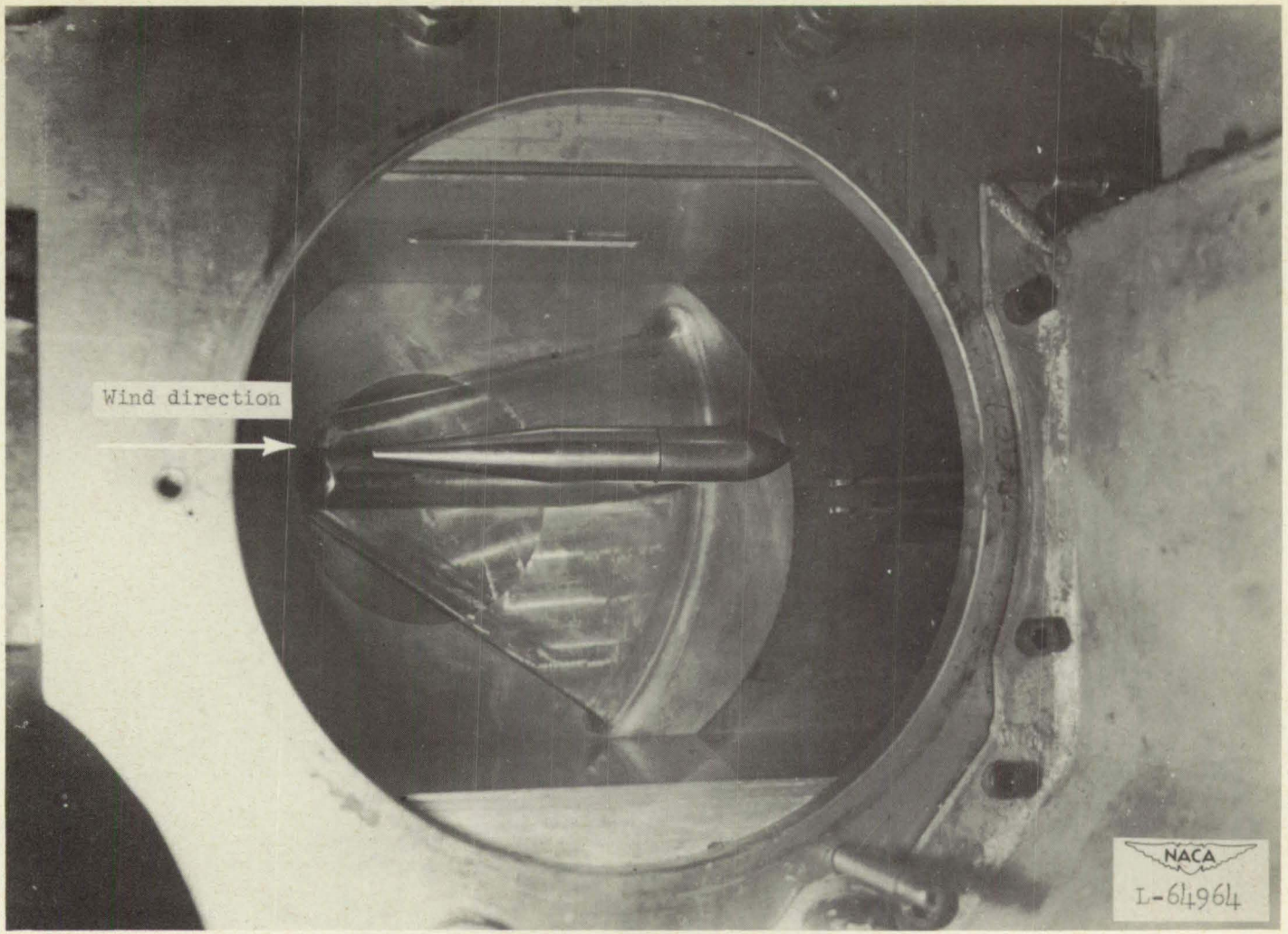

Figure 2.- View of test chamber of Langley 9-inch supersonic tunnel showing a total-pressure tube mounted on swivel apparatus.

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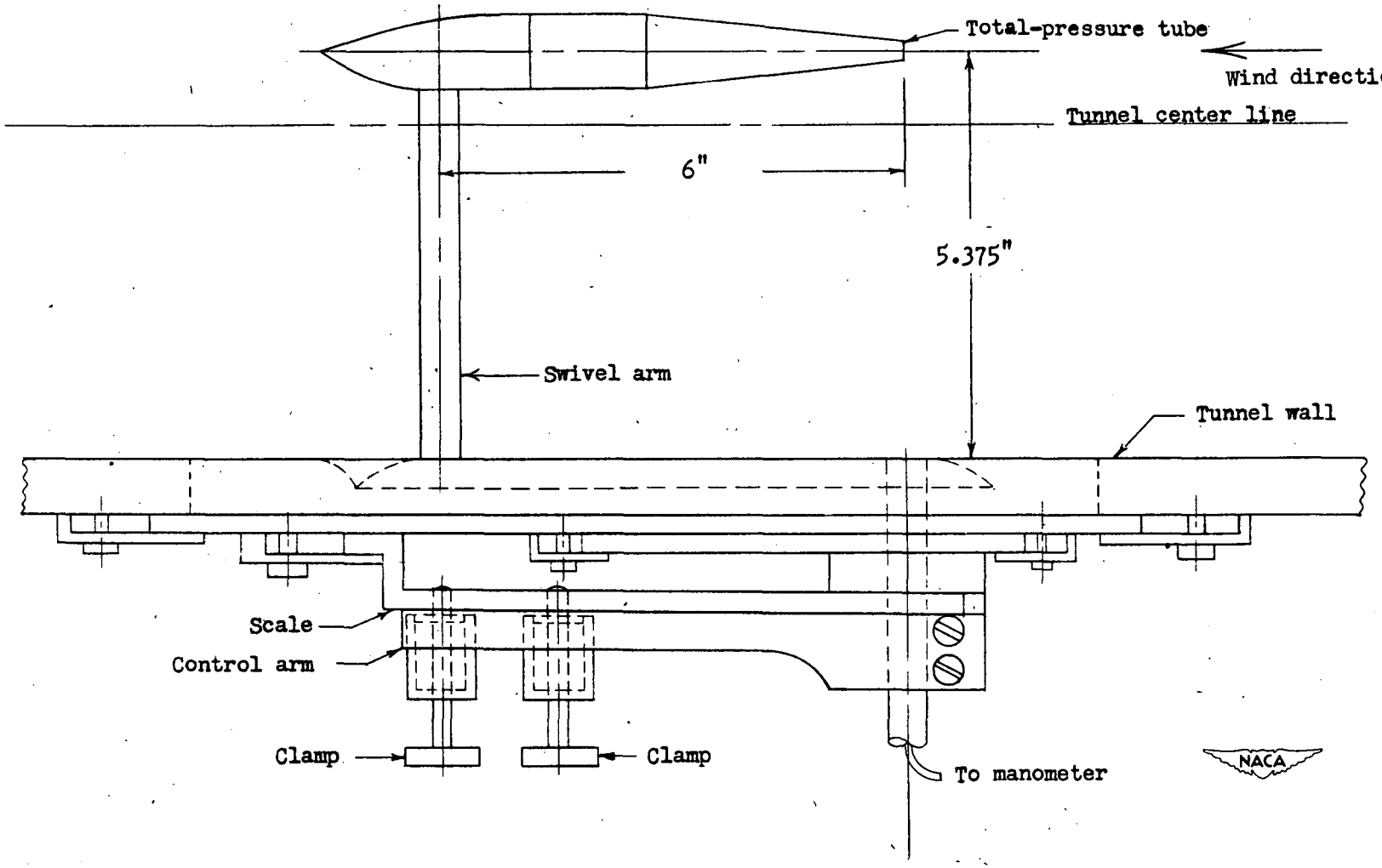

Figure 3.- Diagram of swivel apparatus used for rotating total-pressure tubes through angle-of-attack range.

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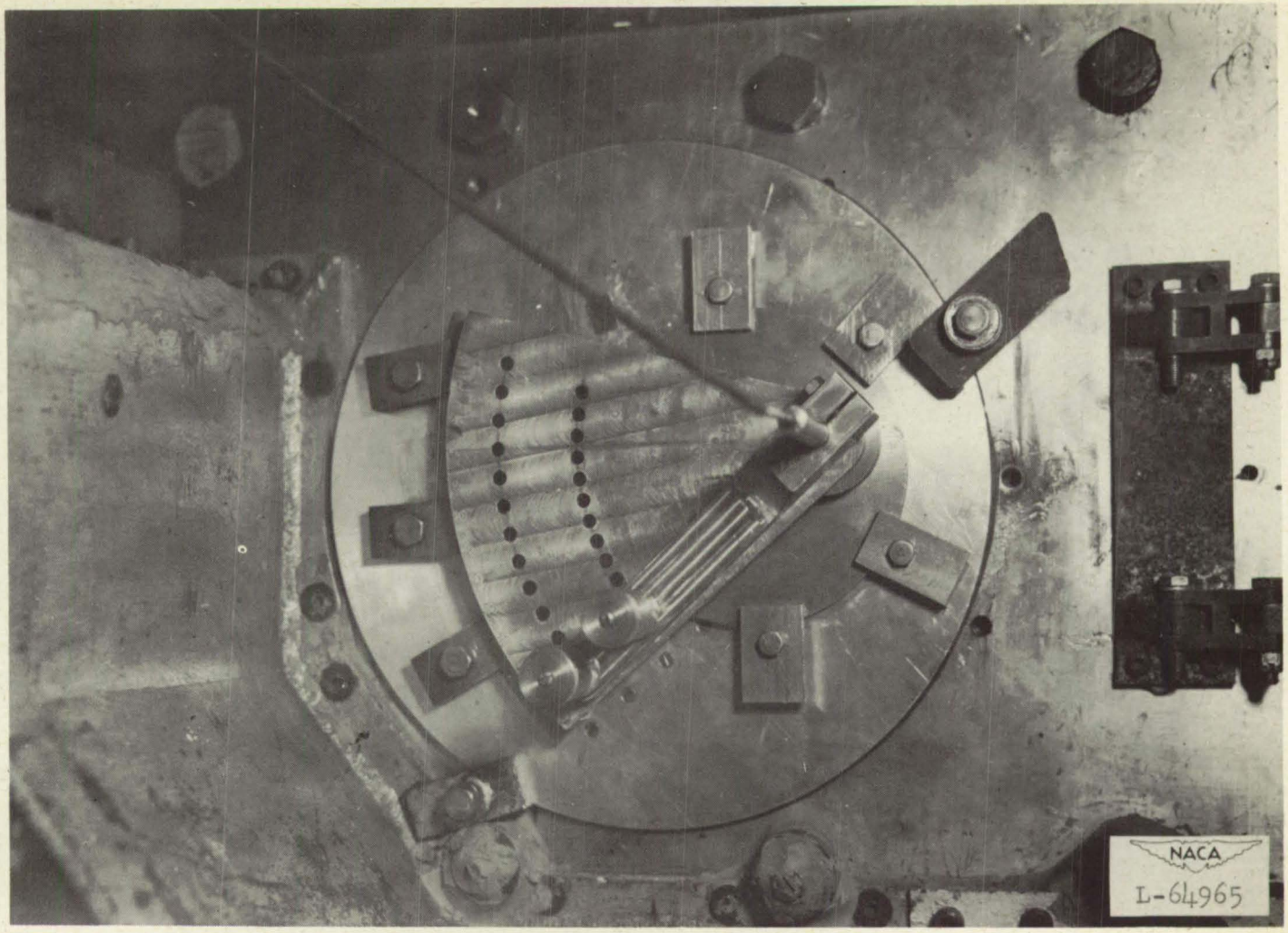

Figure 4.- View of outside tunnel wall showing control arm and angular scale used for fixing the inclination of the total-pressure tubes.

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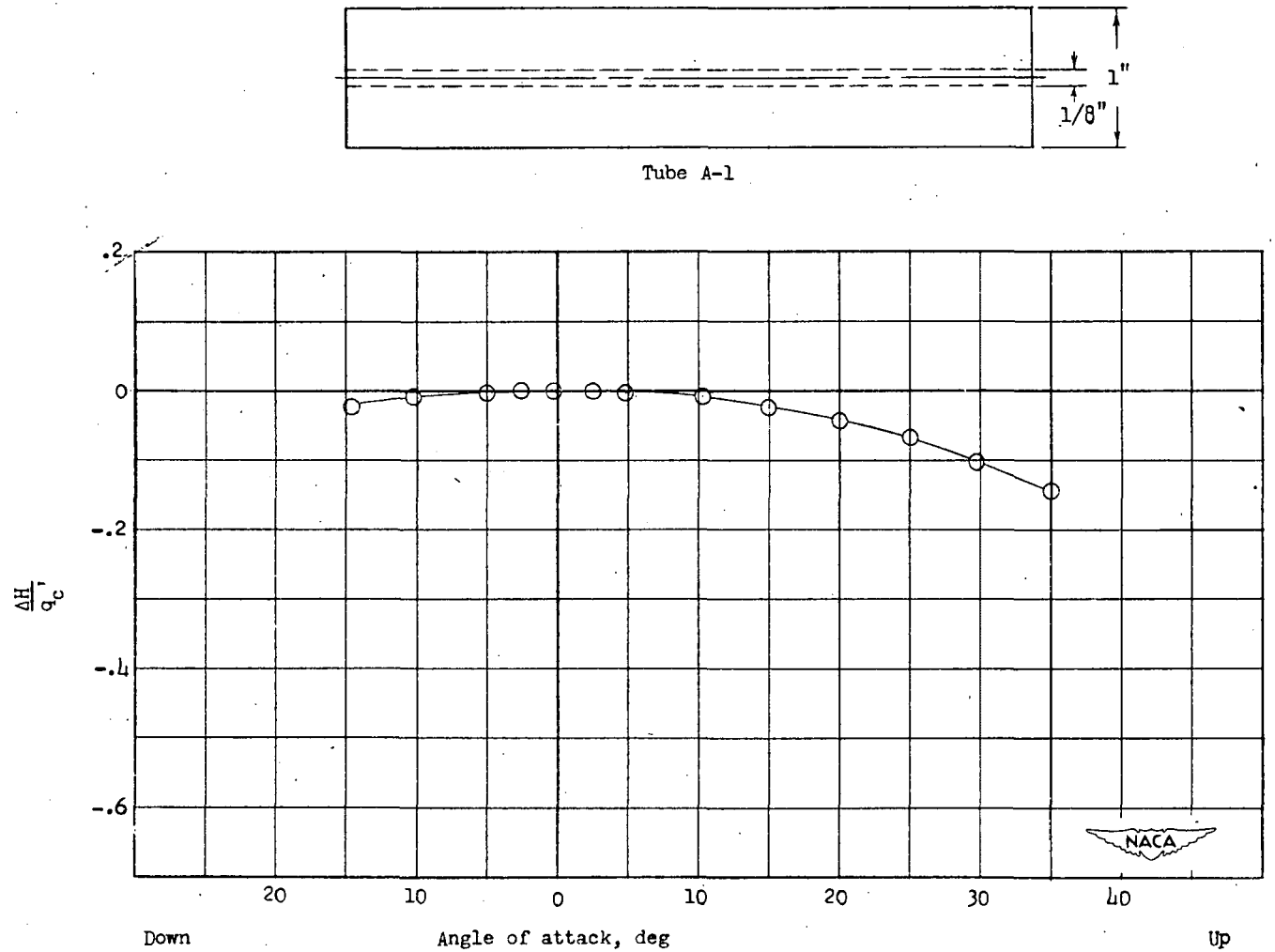
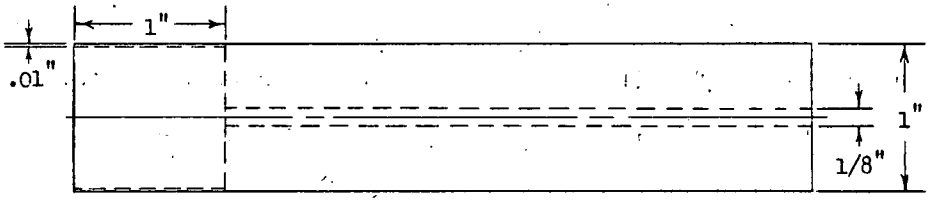


Figure 5.- Variation of total-pressure error with angle of attack.
M = 1.62. Tube A-1.



Tube A-2

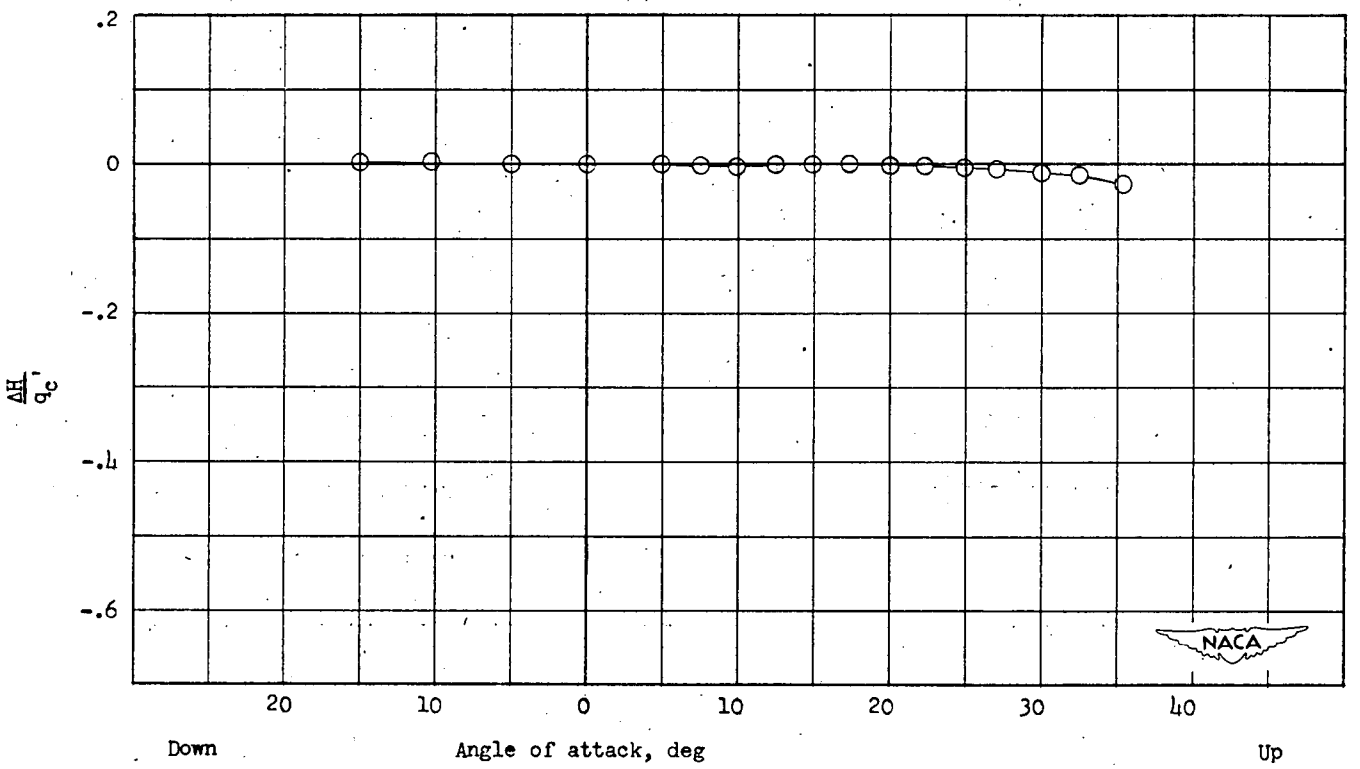
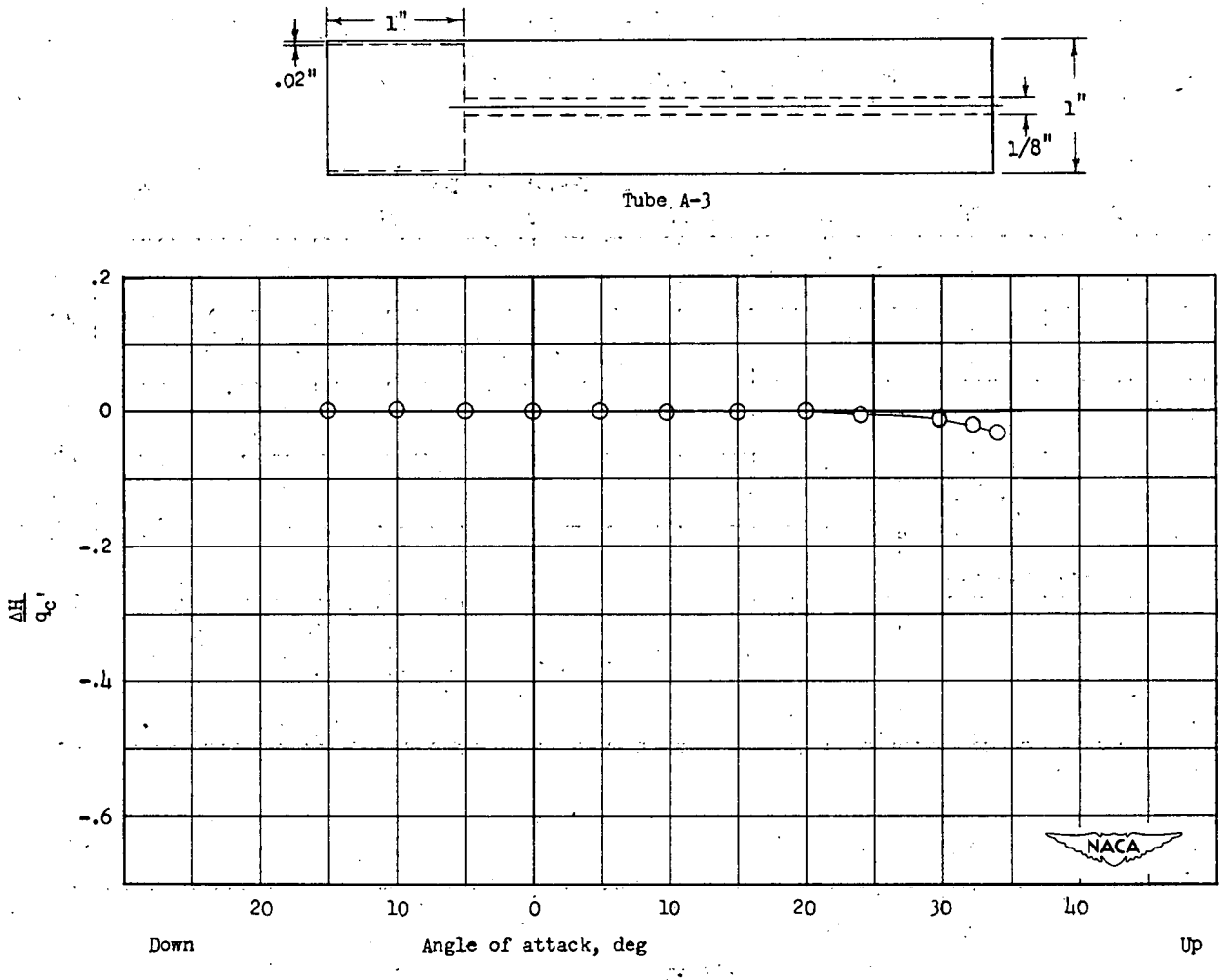
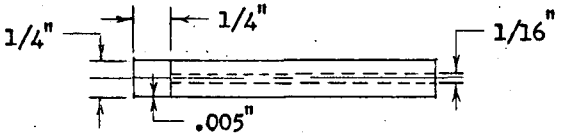


Figure 6.- Variation of total-pressure error with angle of attack. M = 1.62. Tube A-2.

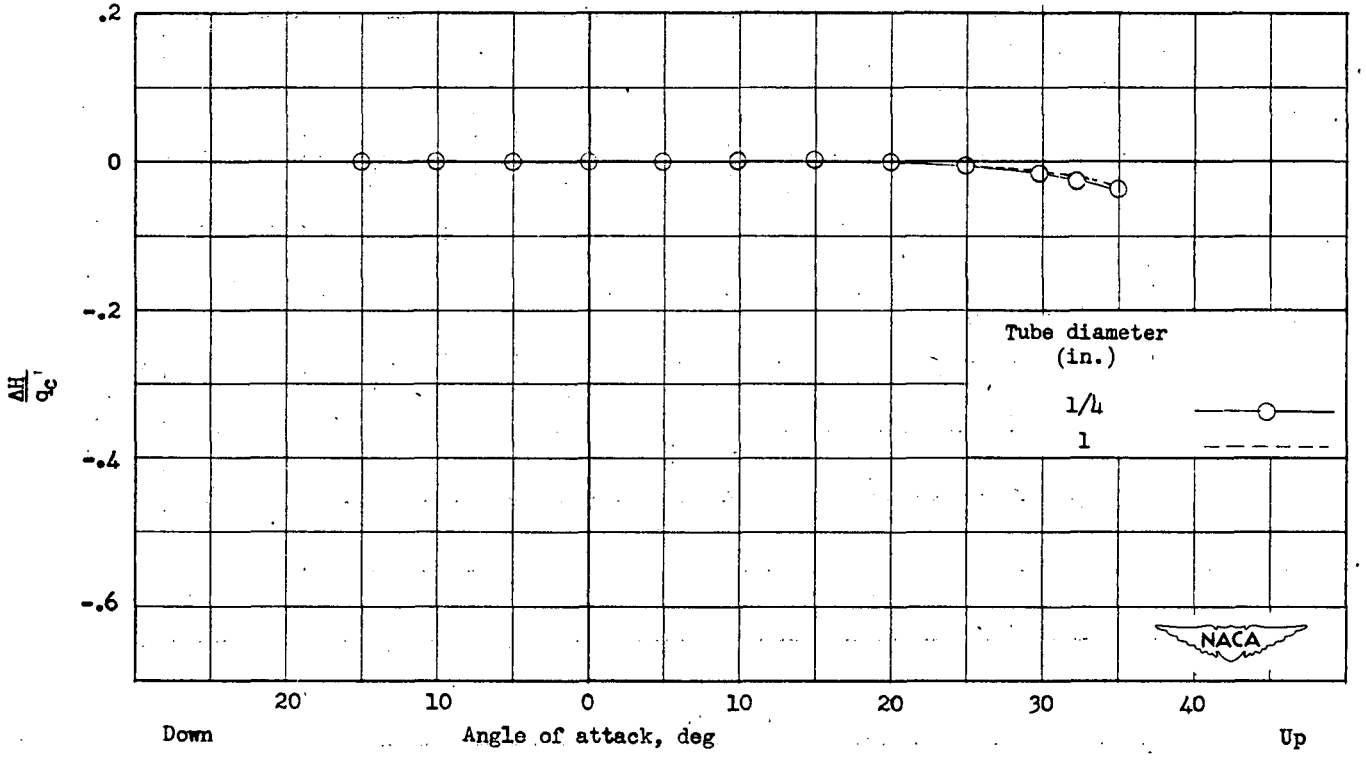


(a) Full-scale tube at M = 1.62.

Figure 7.- Variation of total-pressure error with angle of attack. Tube A-3.

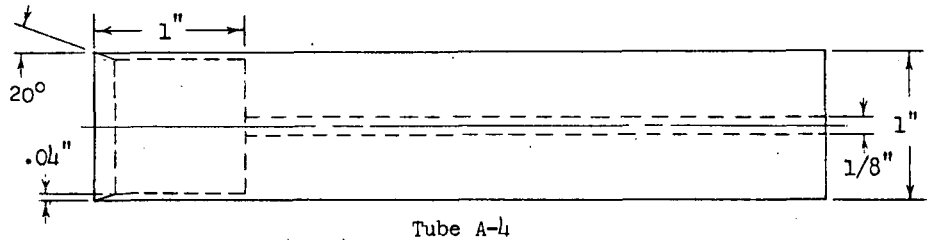


Tube A-3



(b) $\frac{1}{4}$ - scale tube at M = 1.62.

Figure 7.- Concluded.



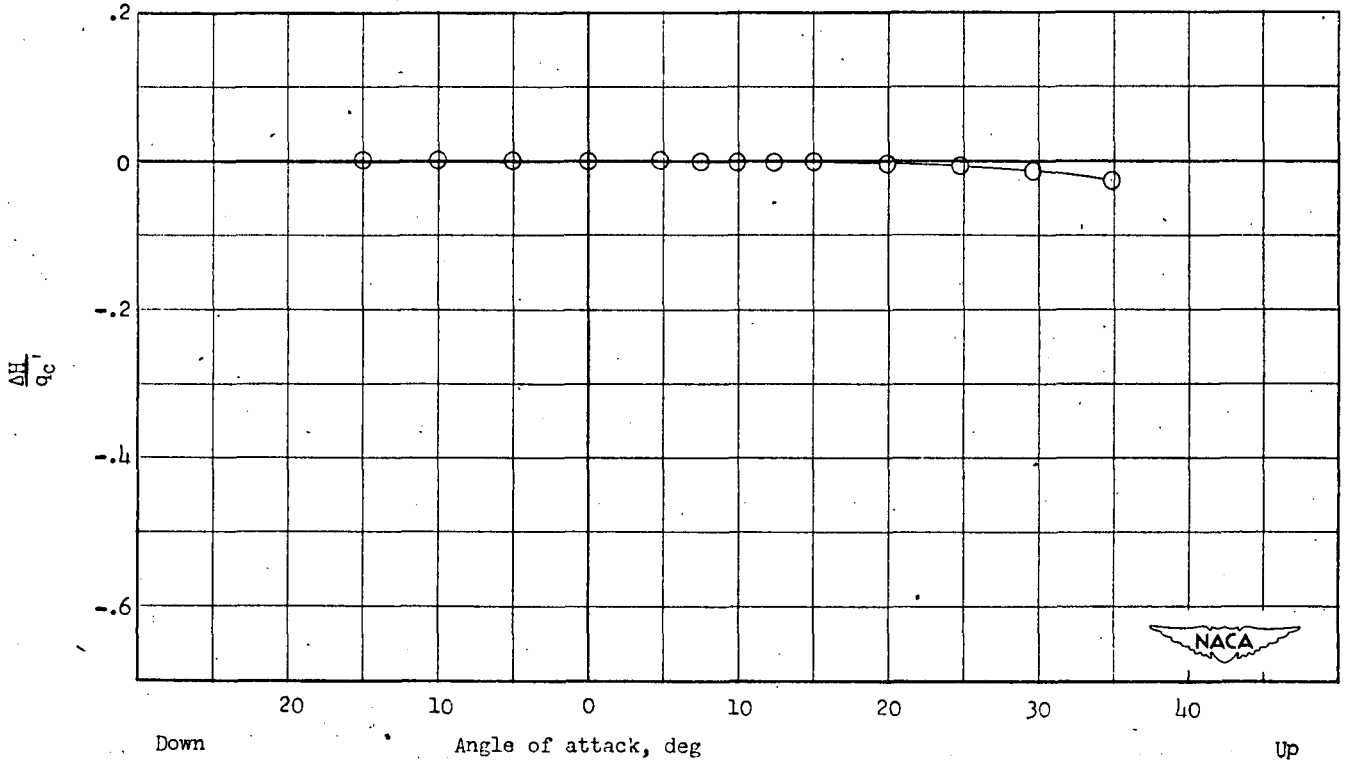
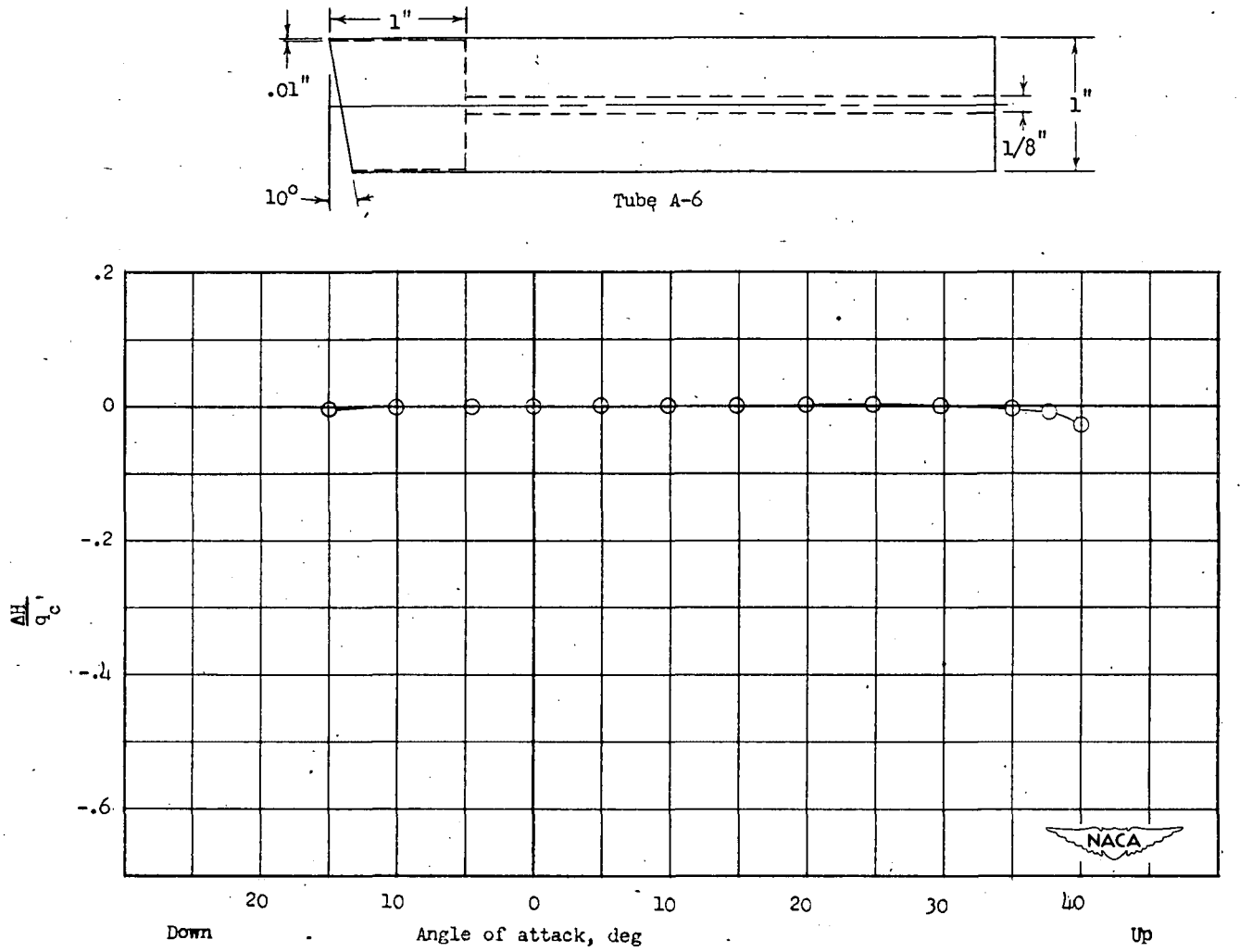
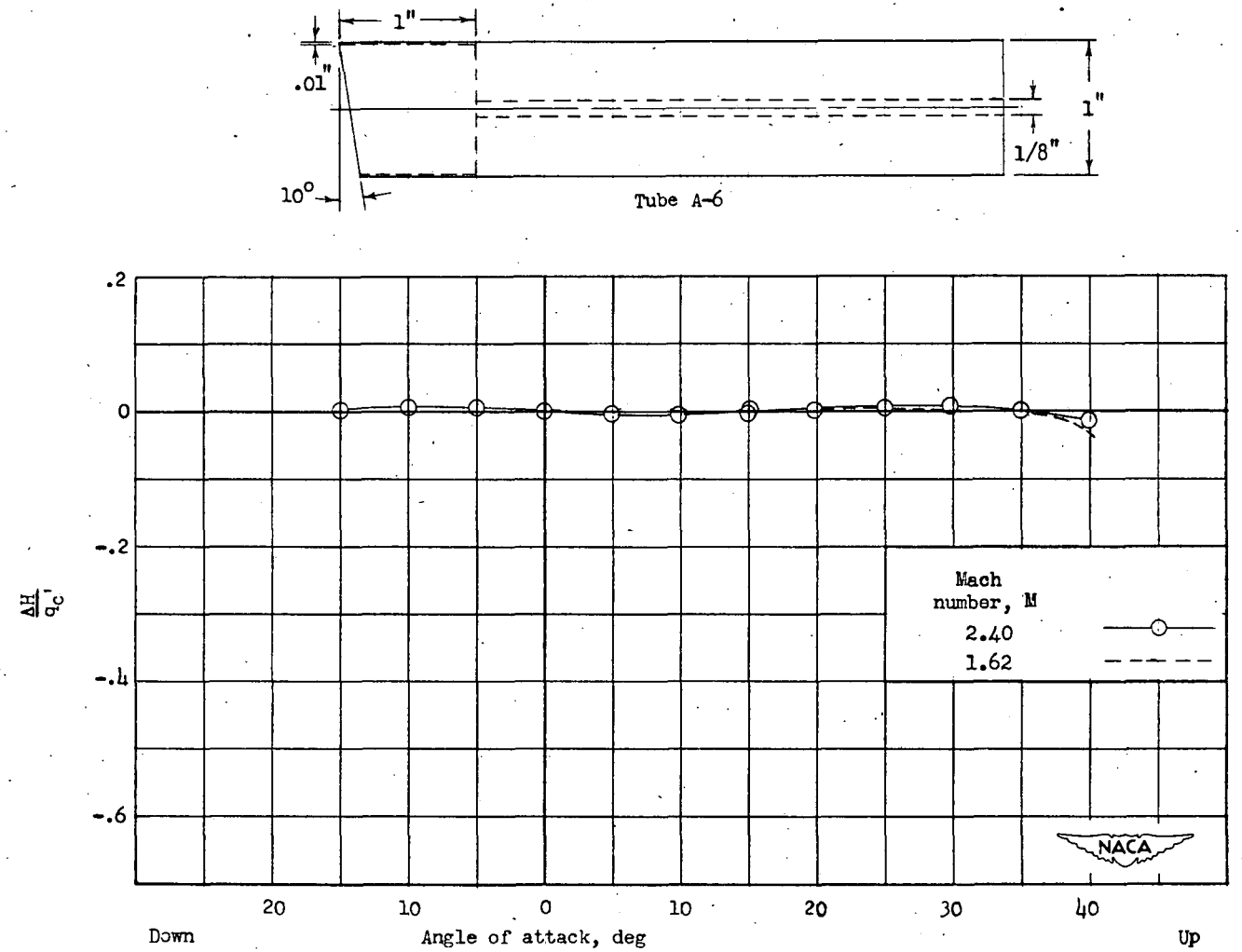


Figure 8.- Variation of total-pressure error with angle of attack.
M = 1.62. Tube A-4.



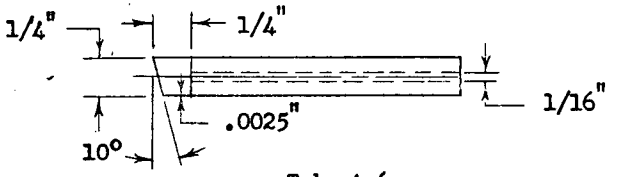
(a) Full-scale tube at M = 1.62.

Figure 9.- Variation of total-pressure error with angle of attack. Tube A-6.

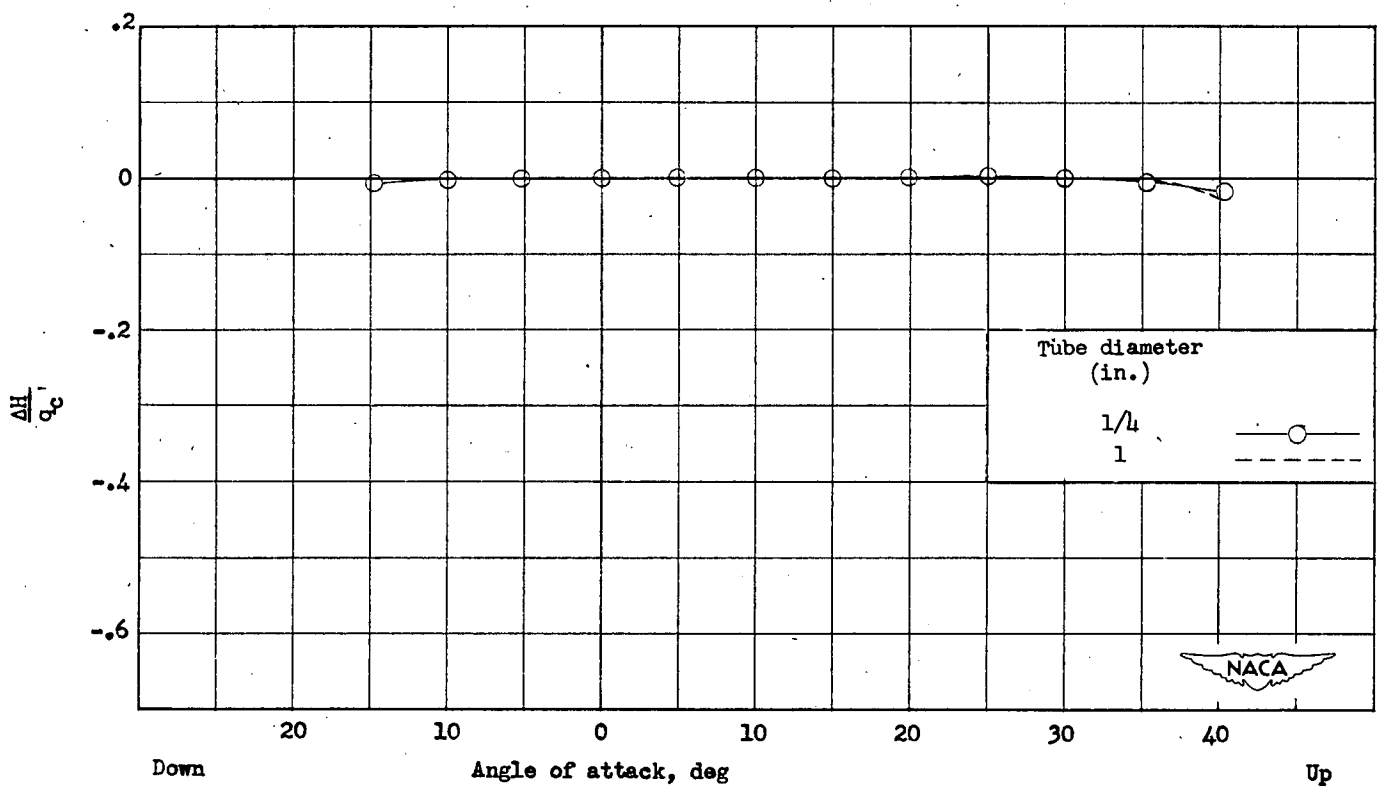


(b) Full-scale tube at M = 2.40.

Figure 9.- Continued.

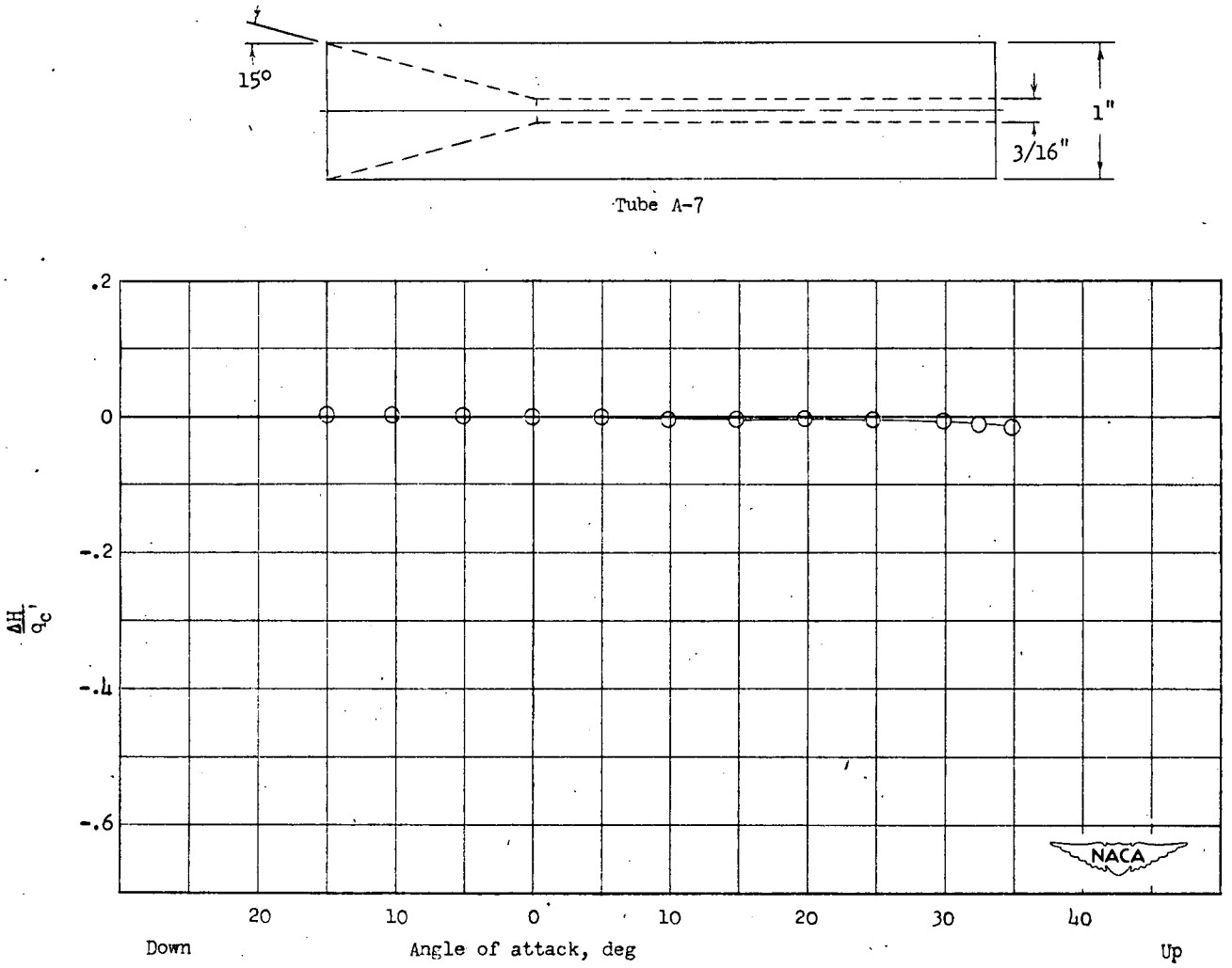


Tube A-6



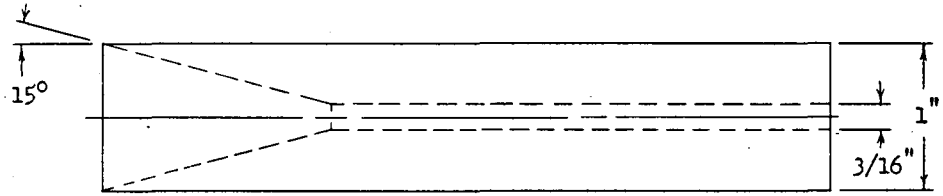
(c) $\frac{1}{4}$ - scale tube at M = 1.62.

Figure 9.- Concluded.

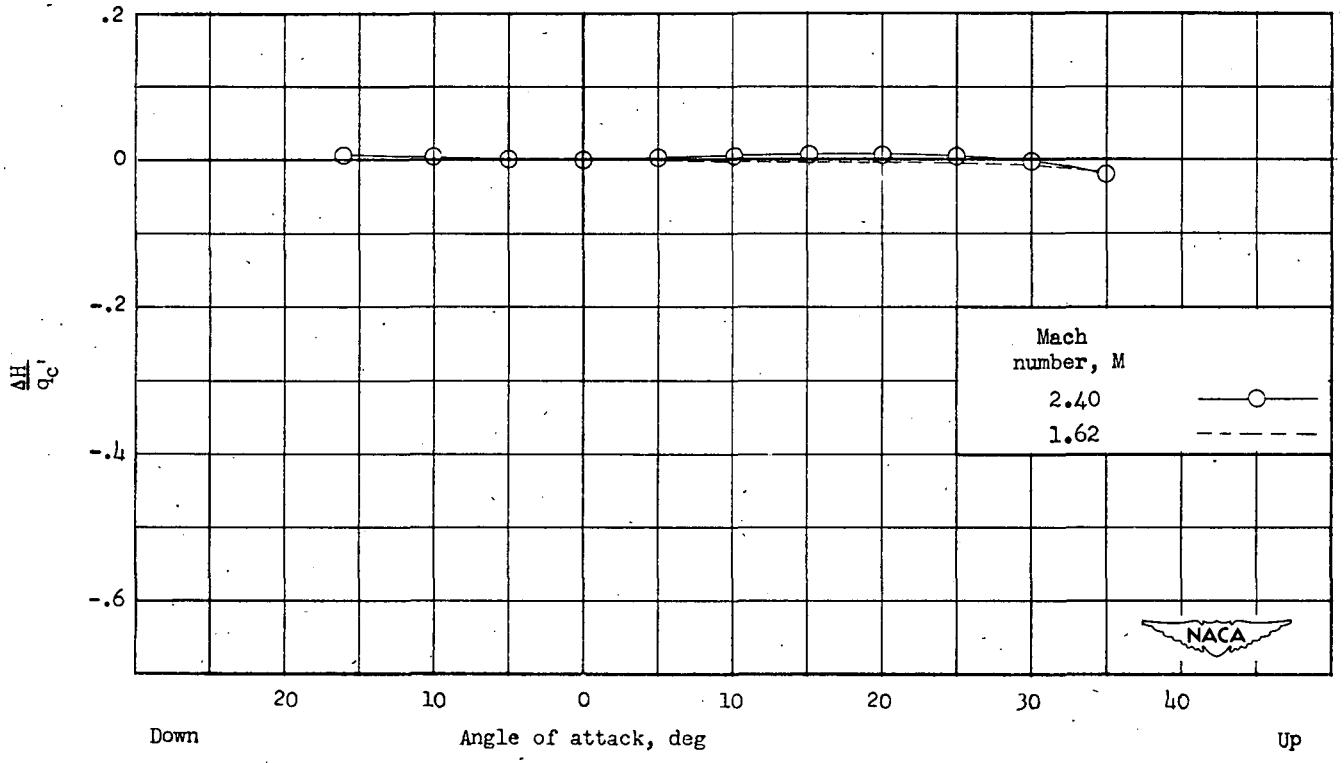


(a) Full-scale tube at M = 1.62.

Figure 10.- Variation of total-pressure error with angle of attack. Tube A-7.

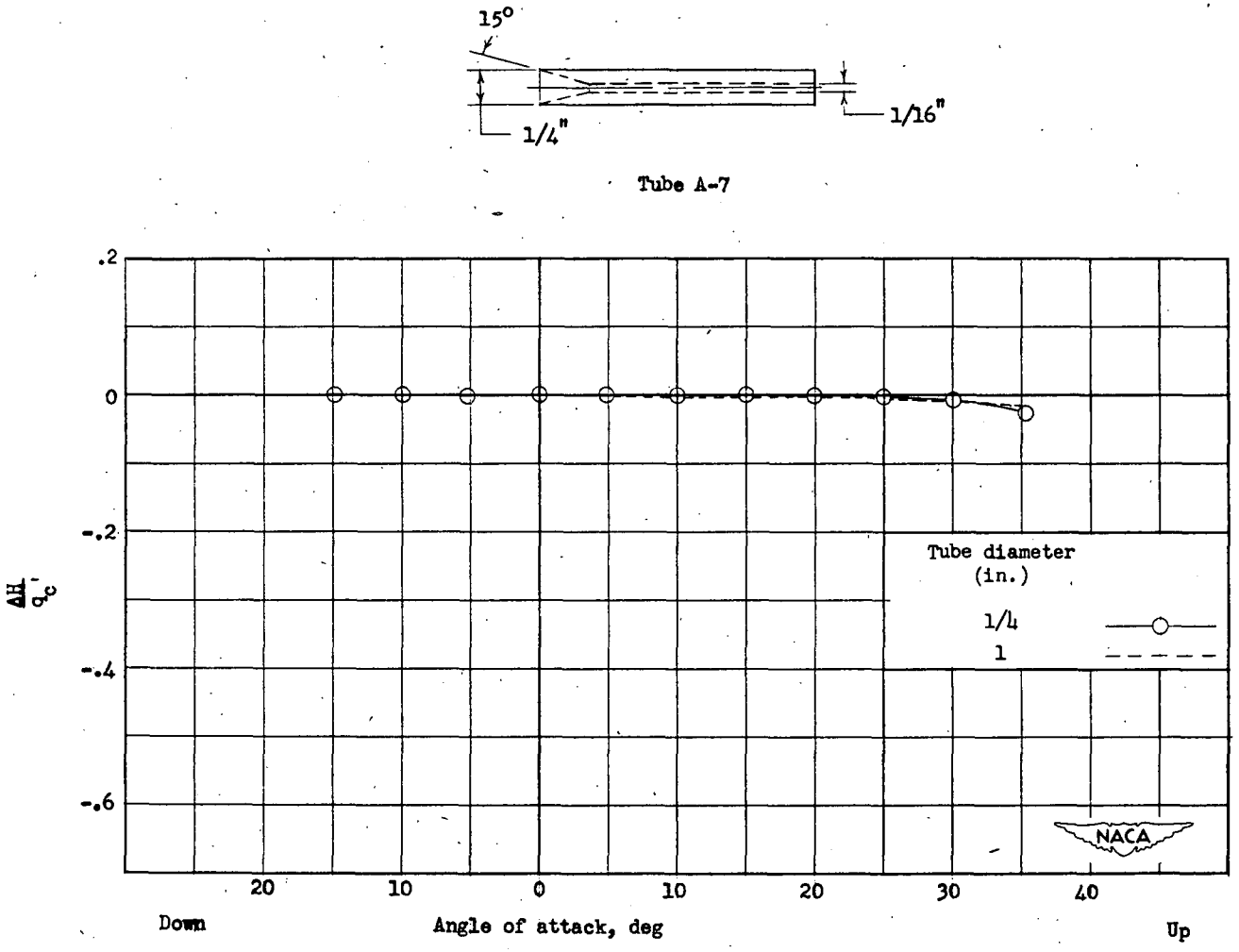


Tube A-7



(b) Full-scale tube at M = 2.40.

Figure 10.- Continued.



(c) $\frac{1}{4}$-scale tube at M = 1.62.

Figure 10.- Concluded.

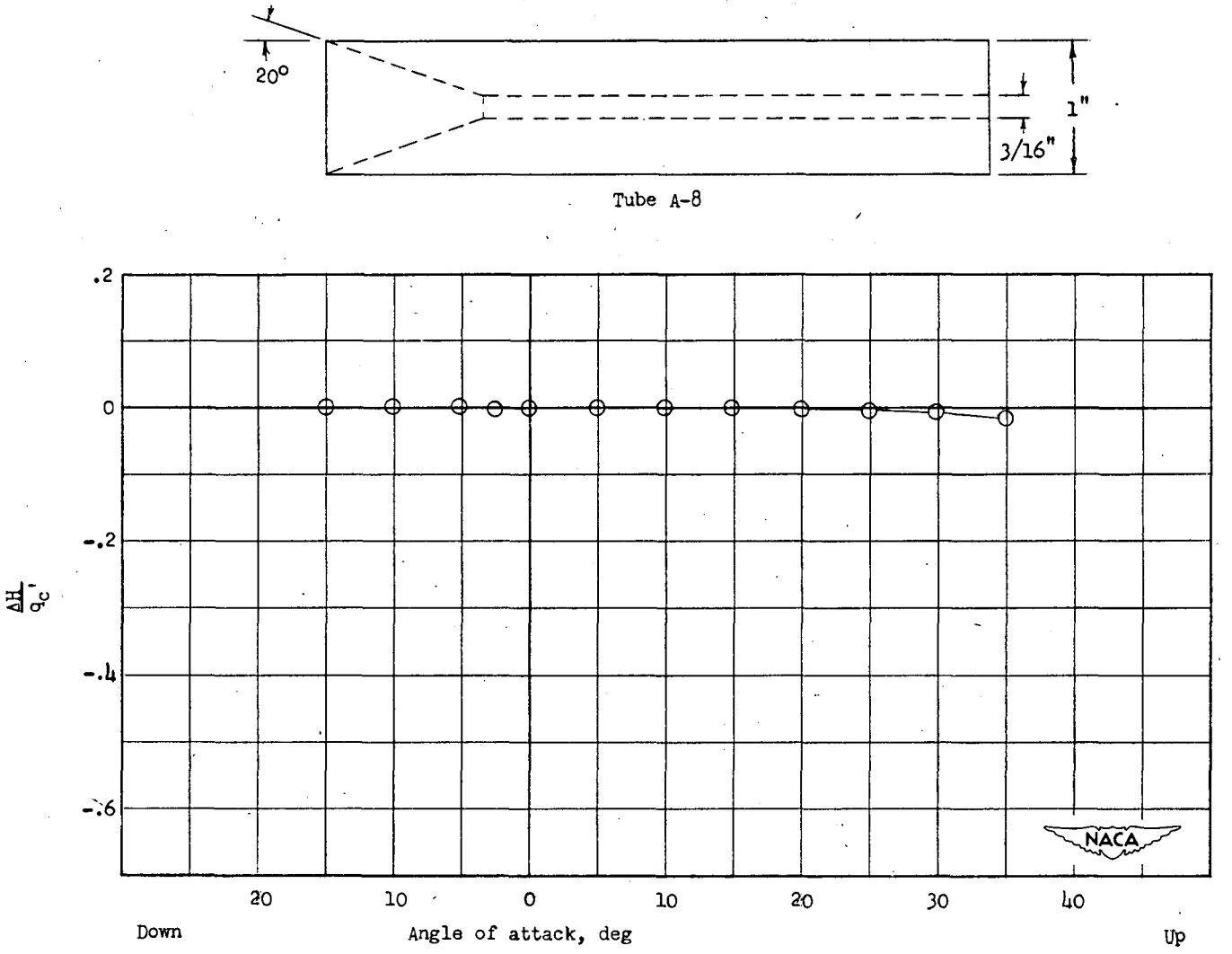
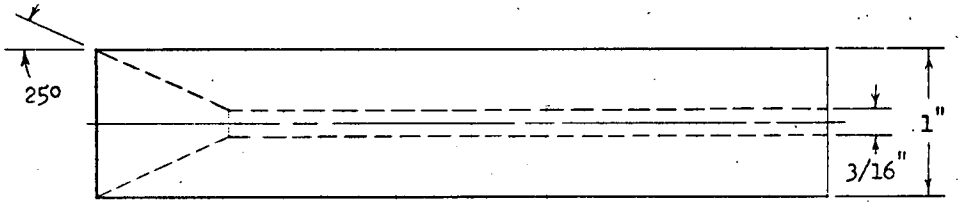


Figure 11.- Variation of total-pressure error with angle of attack. M = 1.62. Tube A-8.



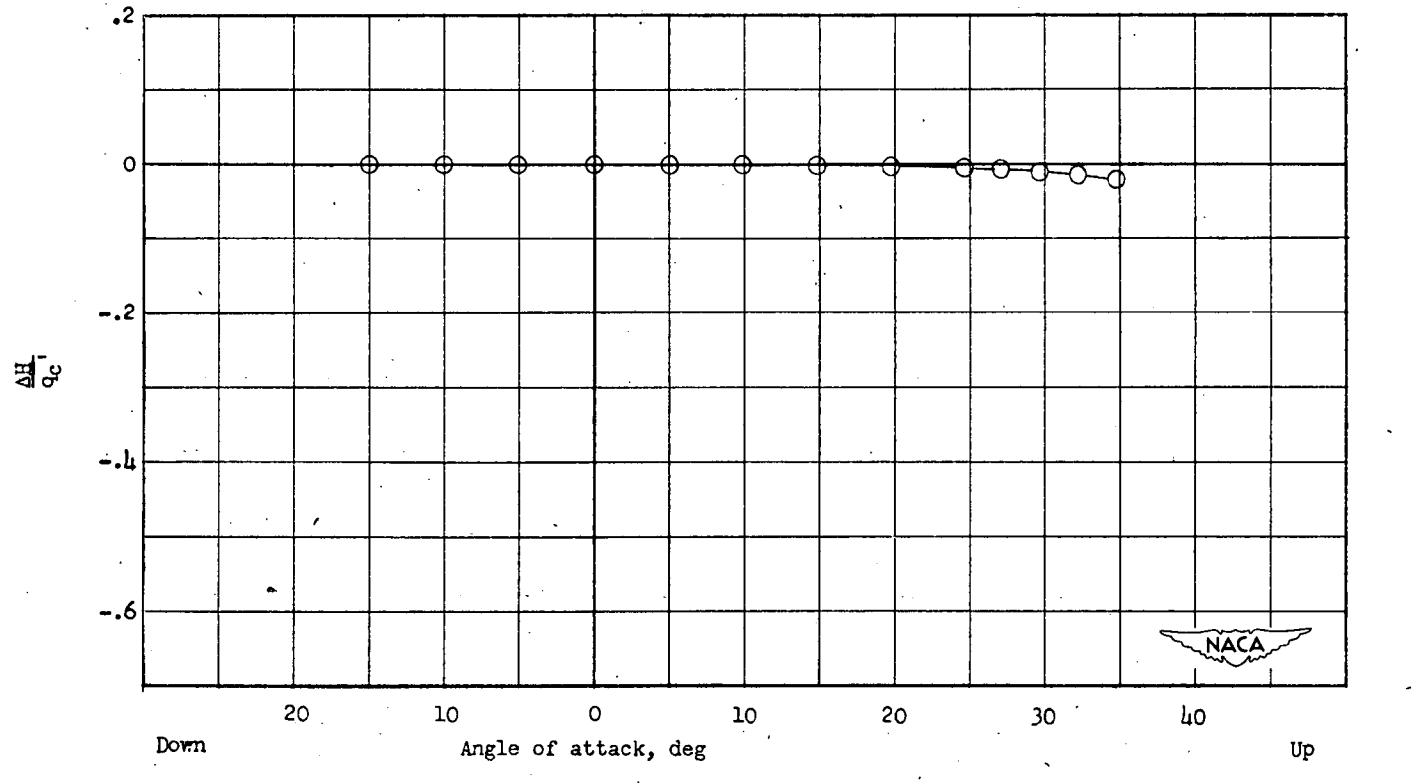
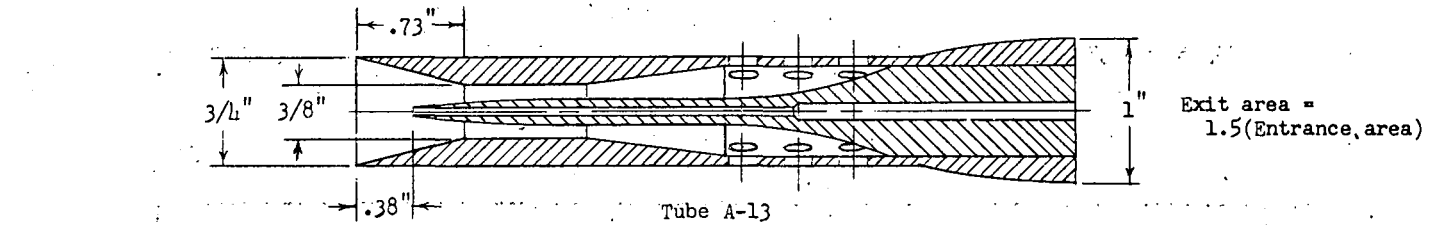
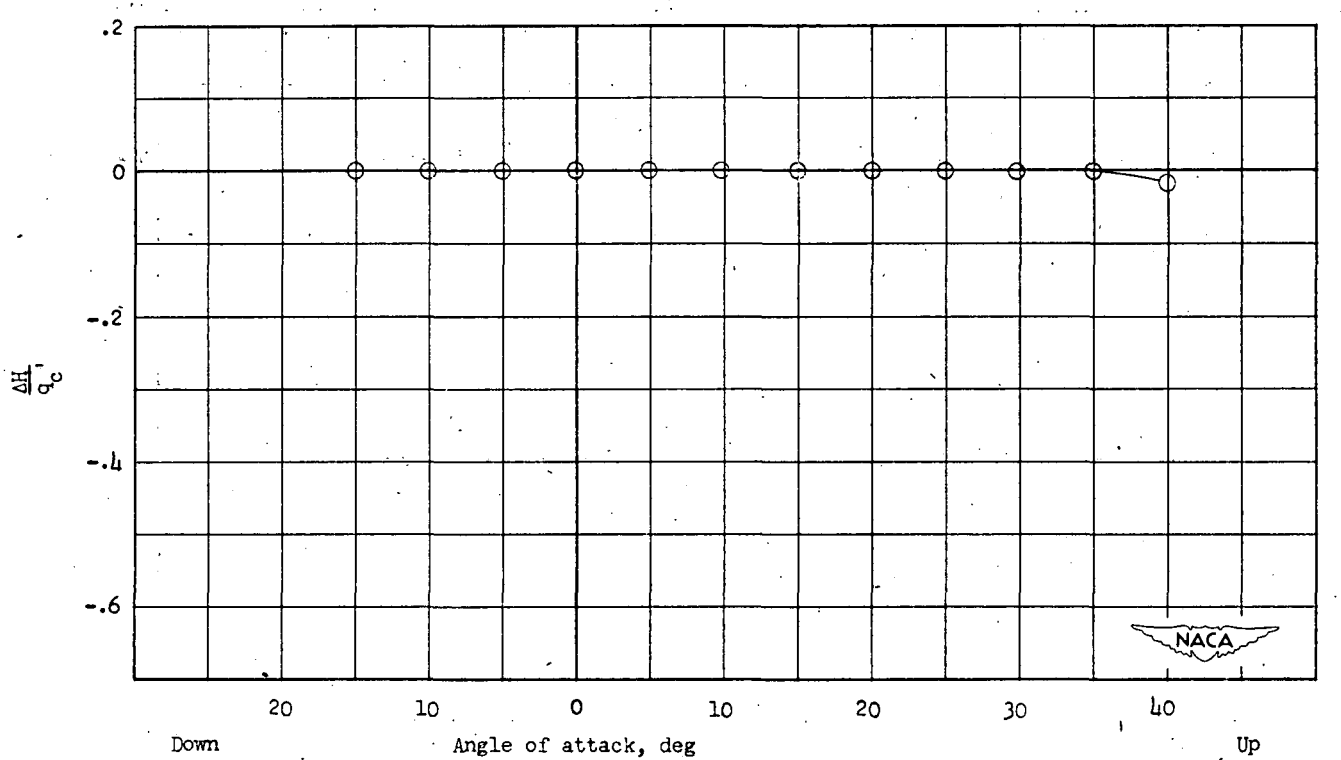


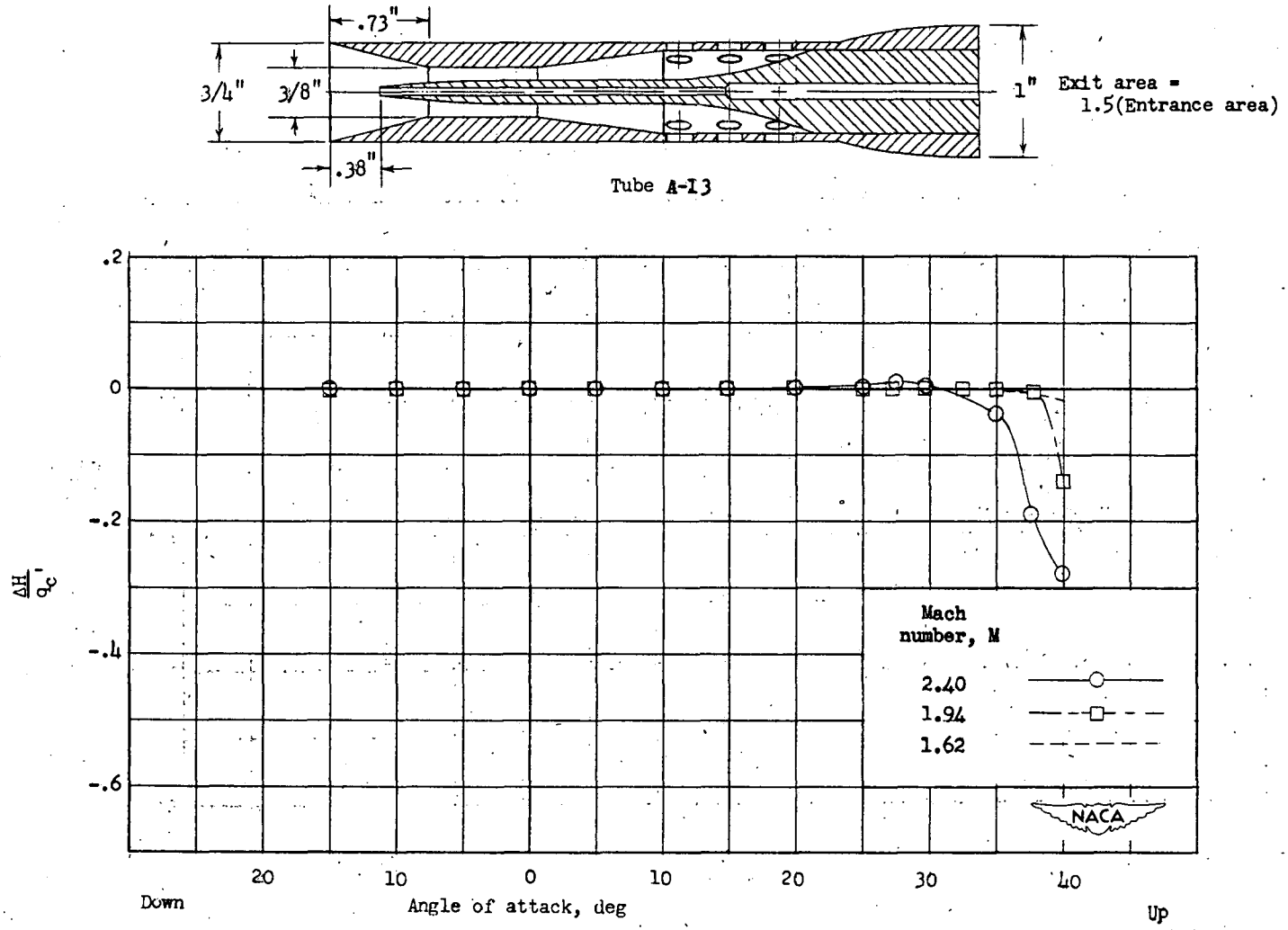
Figure 12.- Variation of total-pressure error with angle of attack. M = 1.62. Tube A-9.





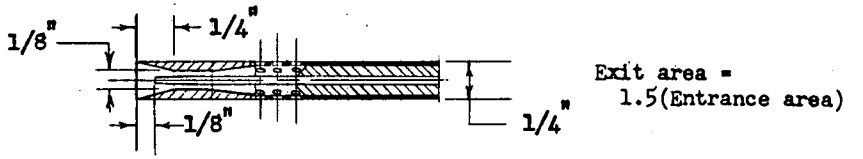
(a) Full-scale tube at M = 1.62.

Figure 13.- Variation of total-pressure error with angle of attack. Tube A-13.

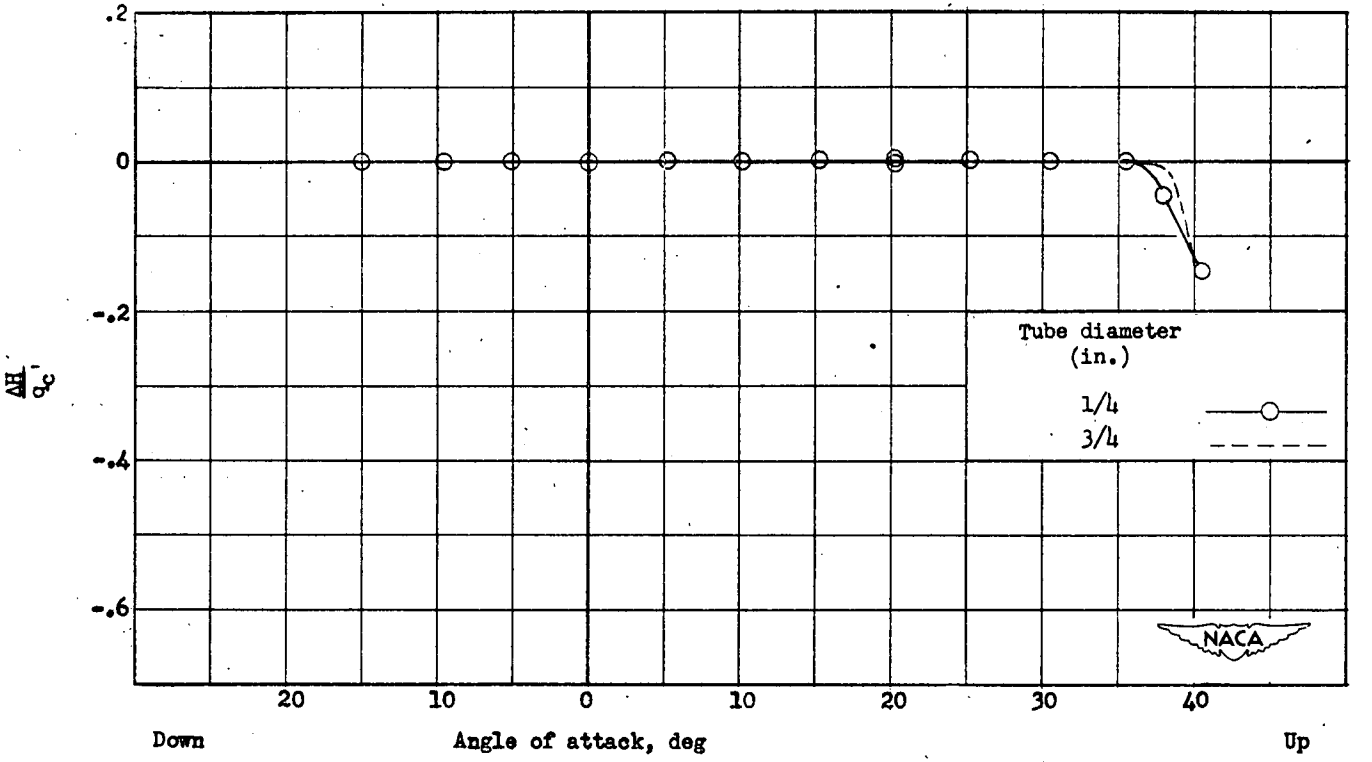


(b) Full-scale tube at M = 1.94 and 2.40.

Figure 13.- Continued.

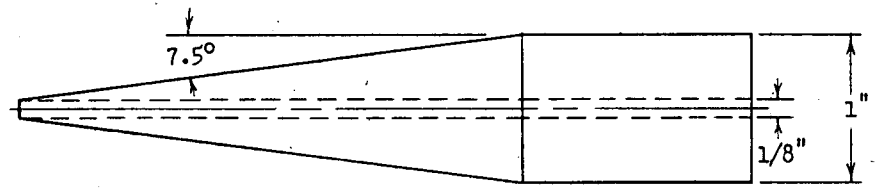


Tube A-13



(c) $\frac{1}{3}$ - scale tube at M = 1.94.

Figure 13.- Concluded.



Tube B-1

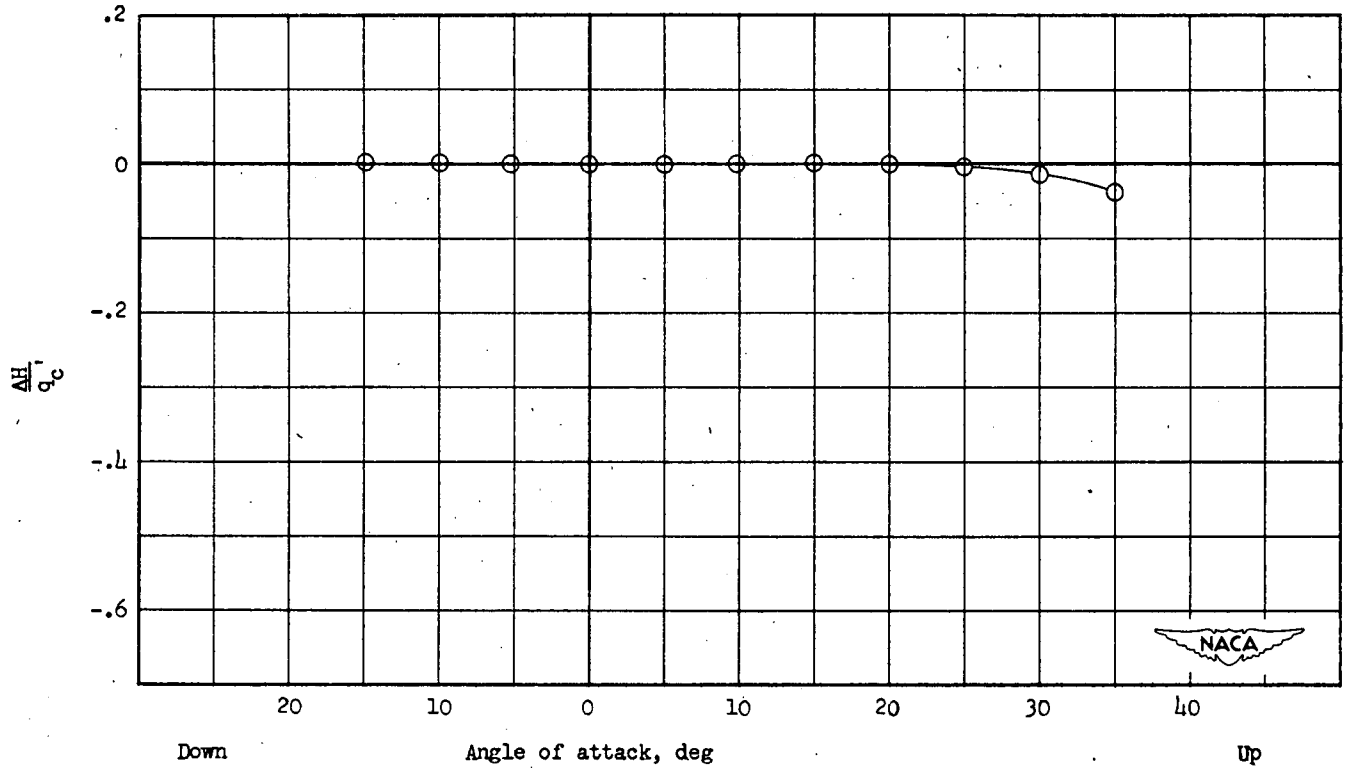
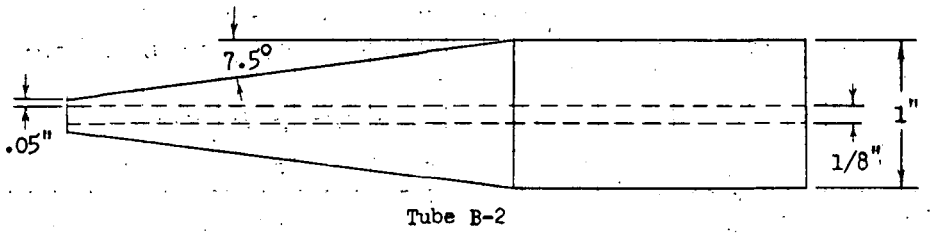


Figure 14.- Variation of total-pressure error with angle of attack. M = 1.62. Tube B-1.



Tube B-2

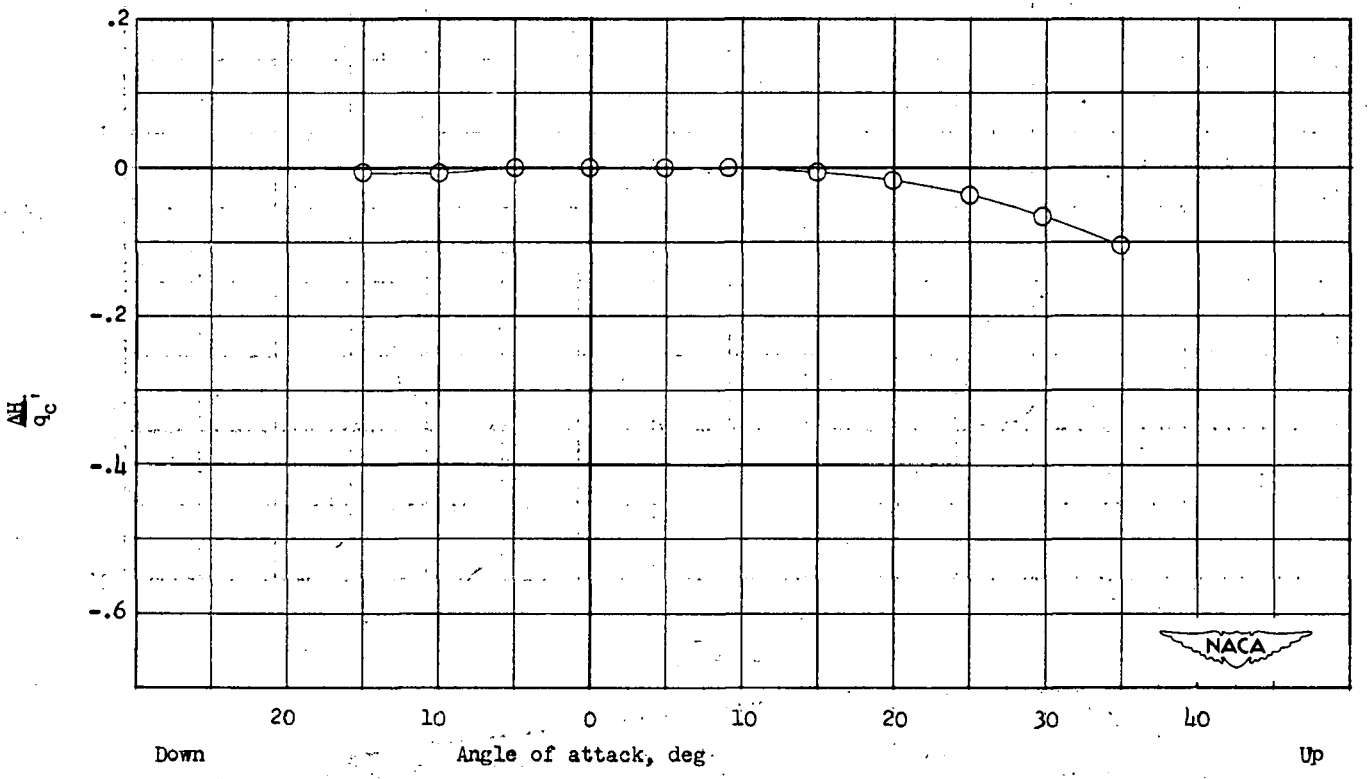


Figure 15.- Variation of total-pressure error with angle of attack. M = 1.62. Tube B-2.

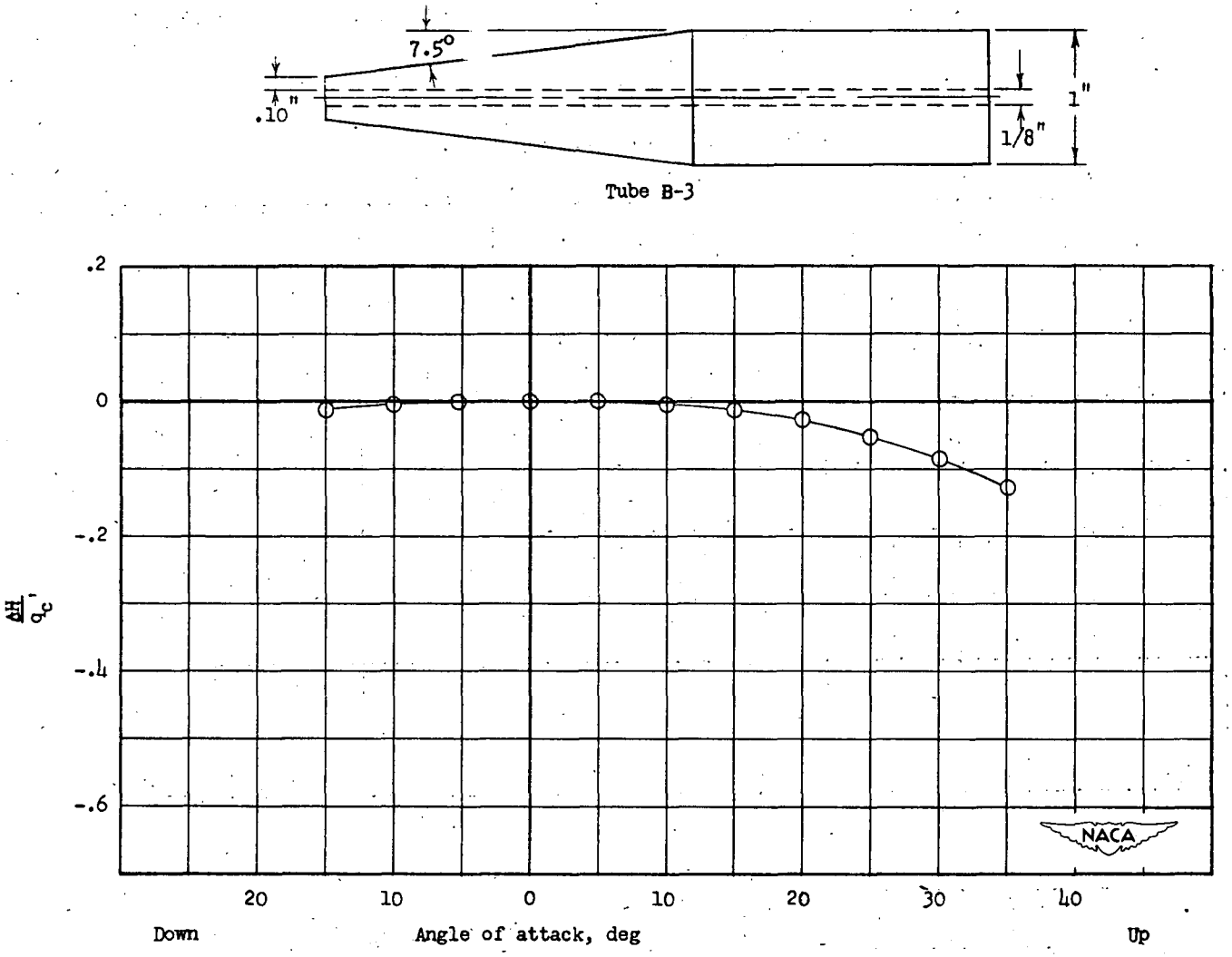
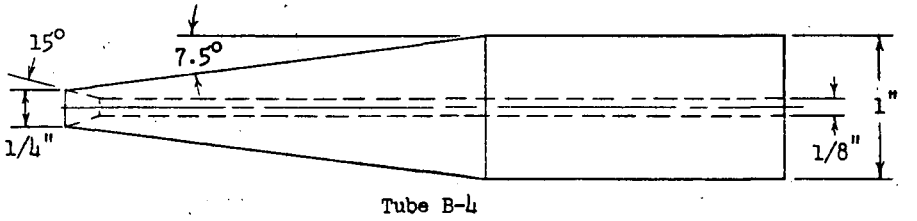
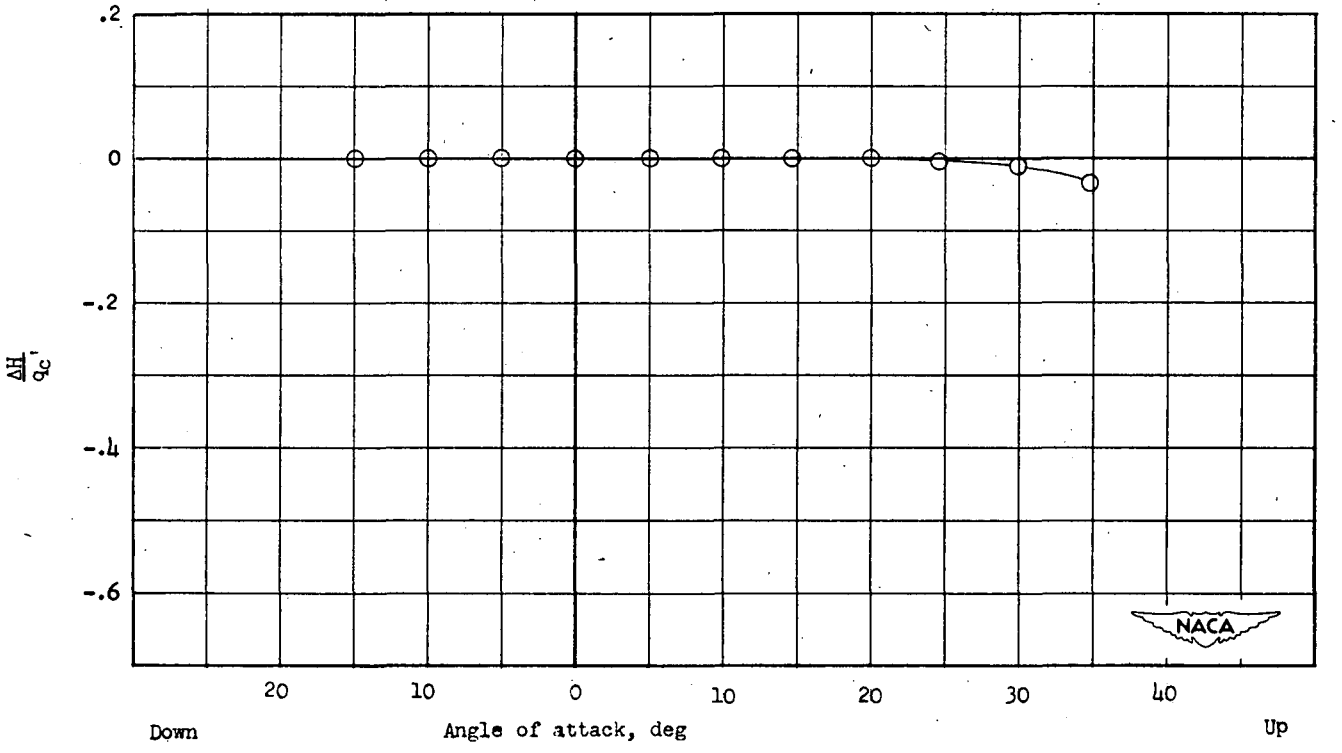


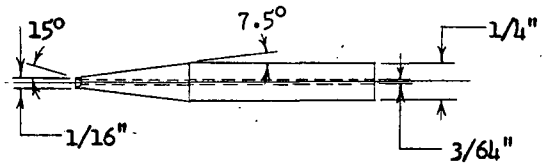
Figure 16.- Variation of total-pressure error with angle of attack. M = 1.62. Tube B-3.



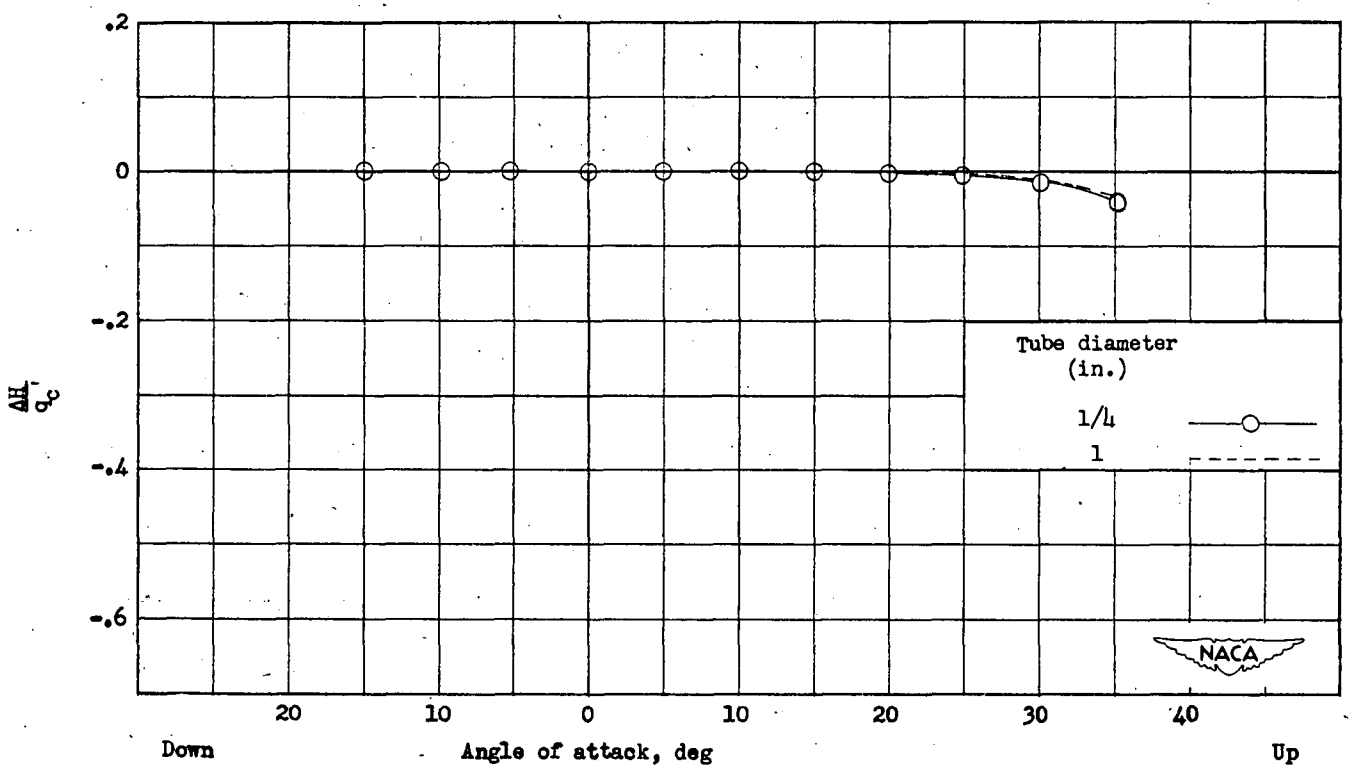


(a) Full-scale tube at M = 1.62.

Figure 17.- Variation of total-pressure error with angle of attack. Tube B-4.

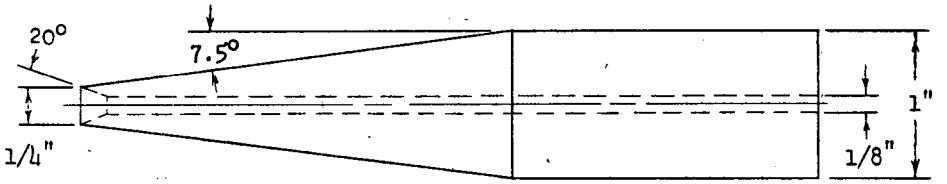


Tube B-4



(b) $\frac{1}{4}$-scale tube at M = 1.62.

Figure 17.- Concluded.



Tube B-5

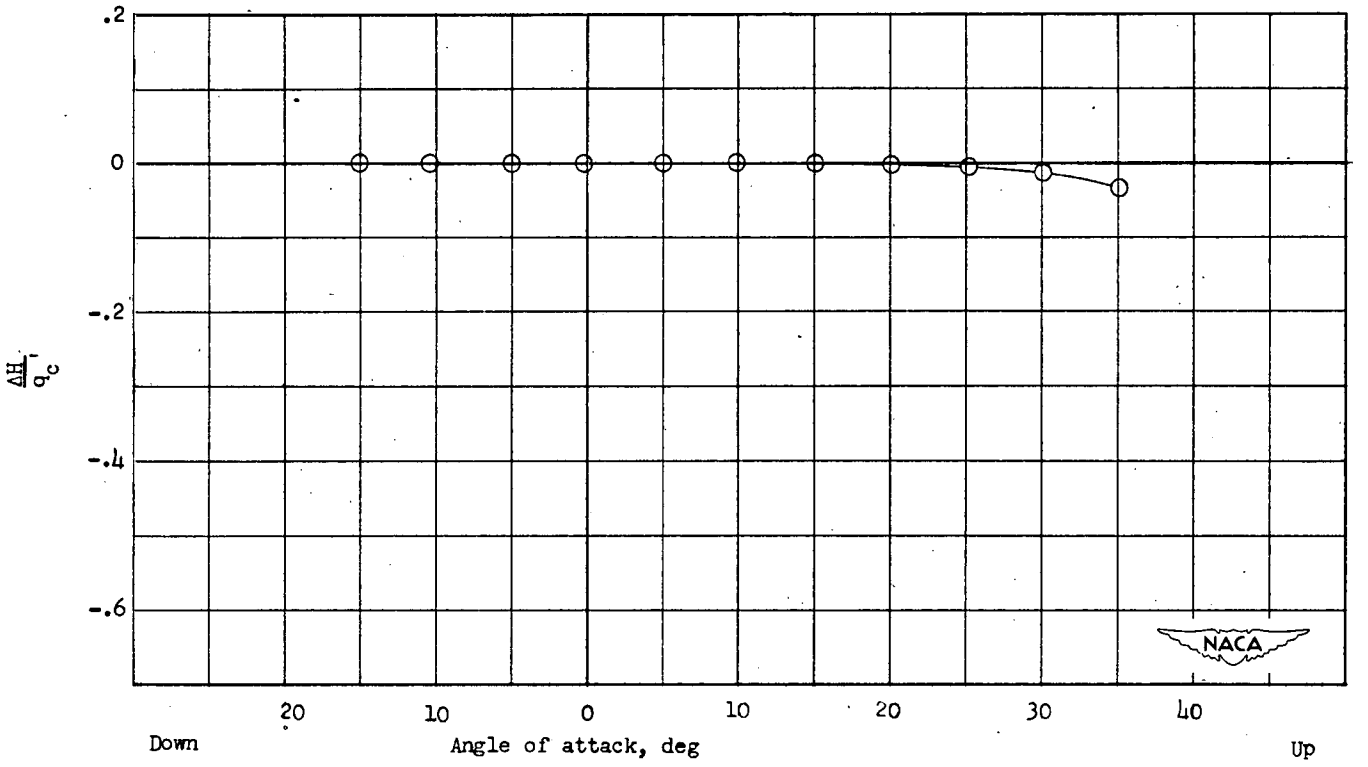
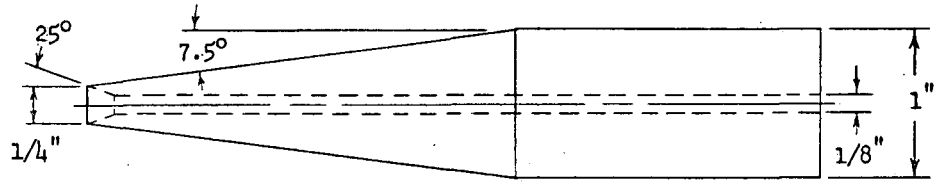


Figure 18.- Variation of total-pressure error with angle of attack. M = 1.62. Tube B-5.



Tube B-6

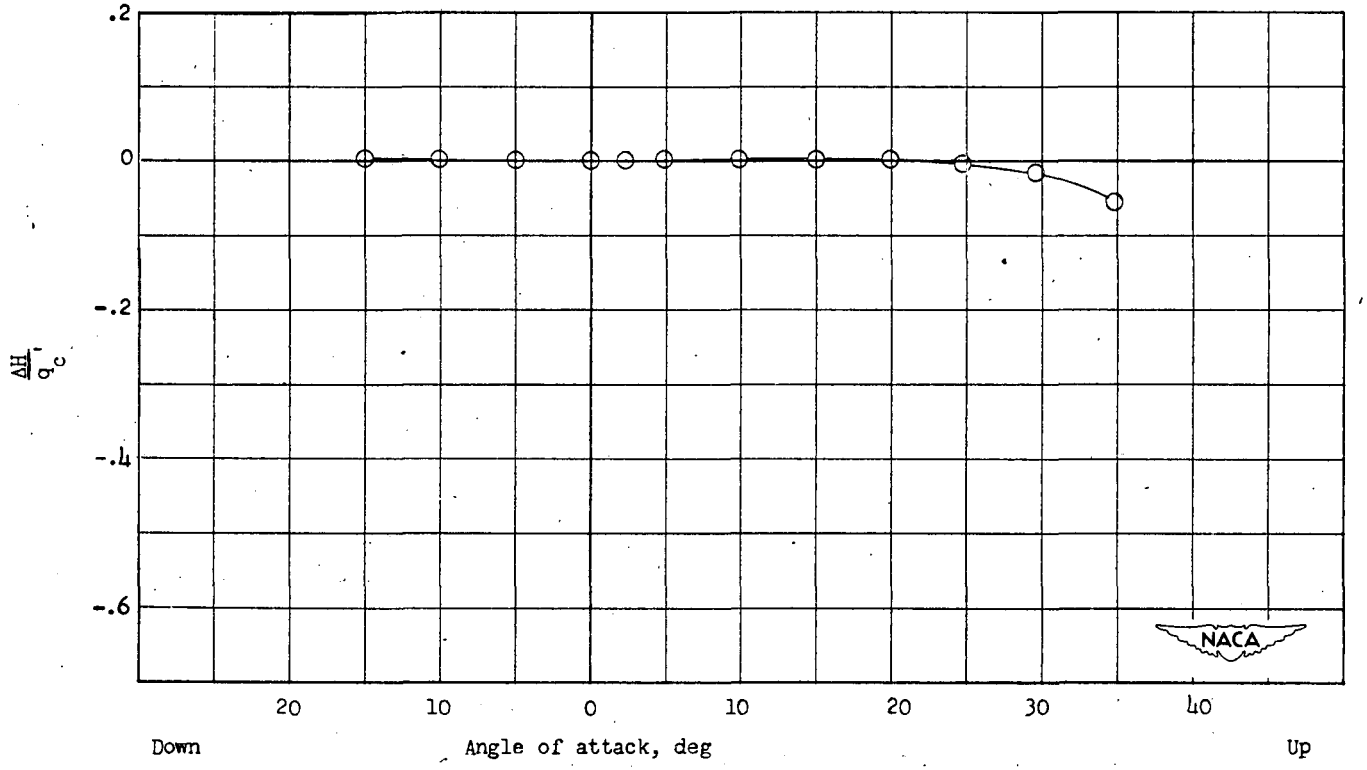
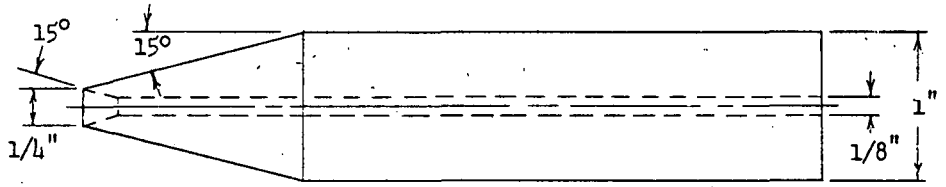


Figure 19.- Variation of total-pressure error with angle of attack.
M = 1.62. Tube B-6.



Tube C-6

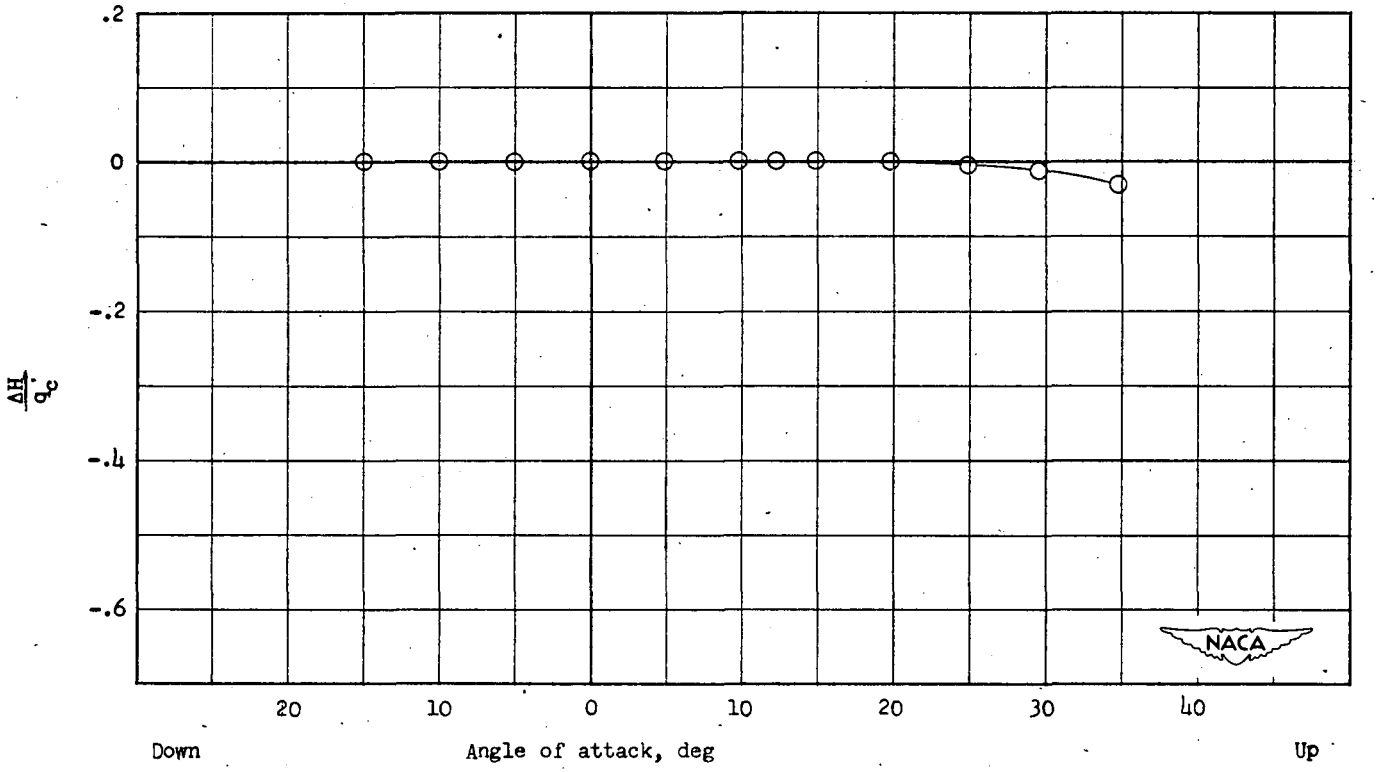
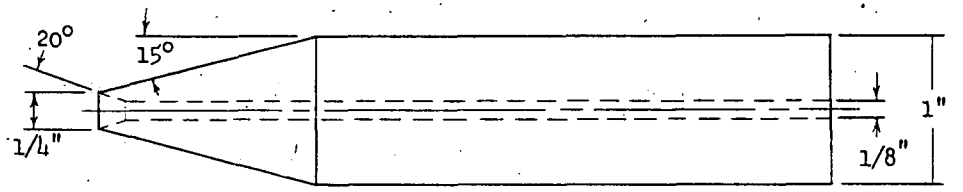


Figure 20.- Variation of total-pressure error with angle of attack. M = 1.62. Tube C-6.



Tube C-7

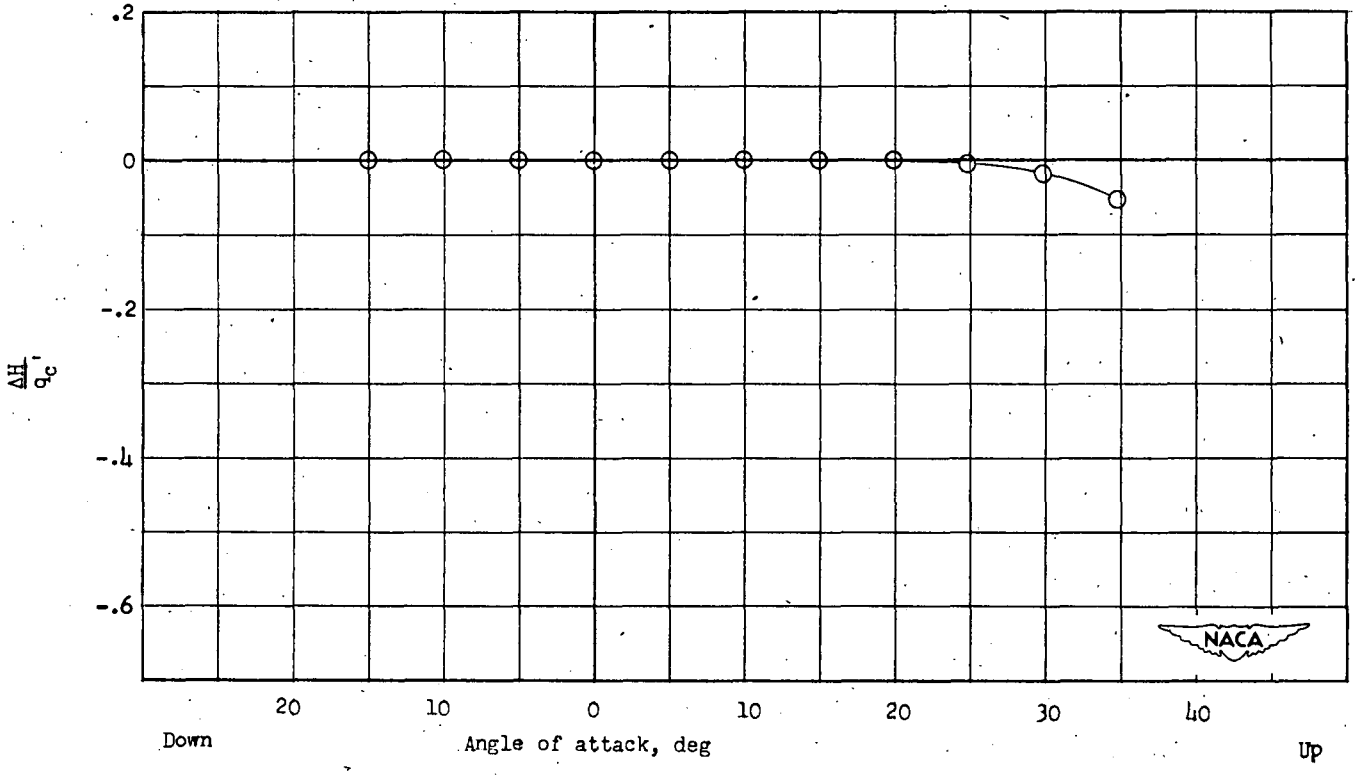
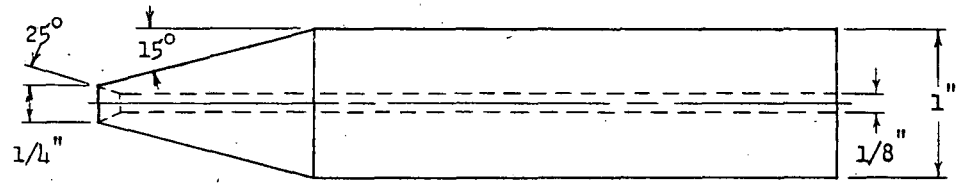


Figure 21.- Variation of total-pressure error with angle of attack. M = 1.62. Tube C-7.



Tube C-8

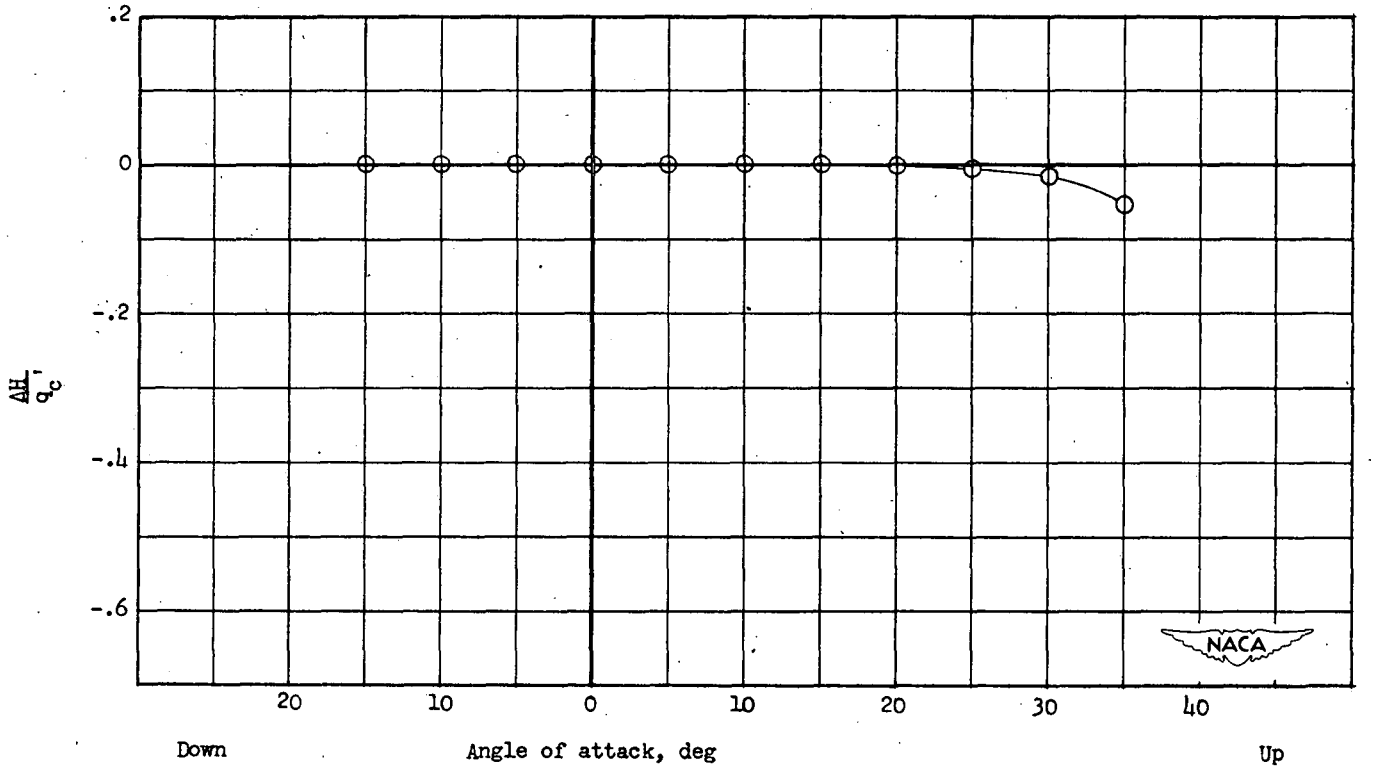
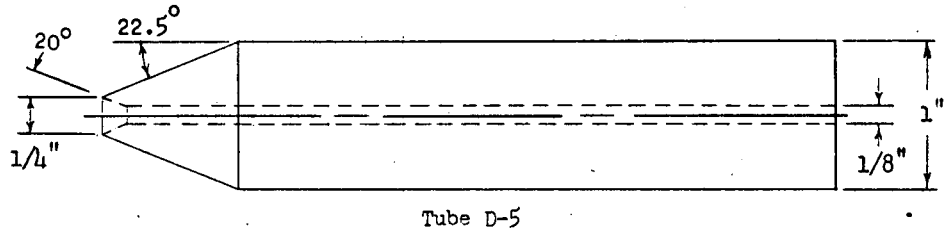


Figure 22.- Variation of total-pressure error with angle of attack. M = 1.62. Tube C-8.



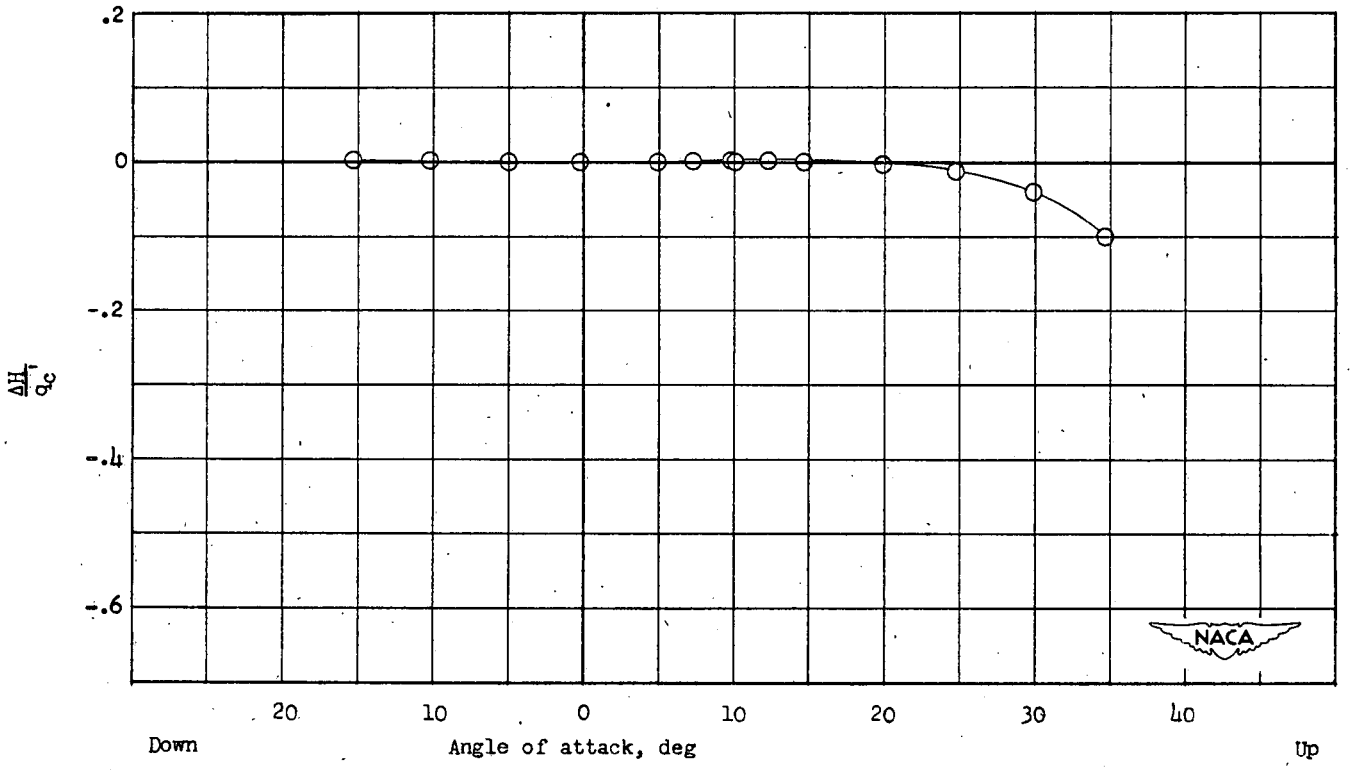
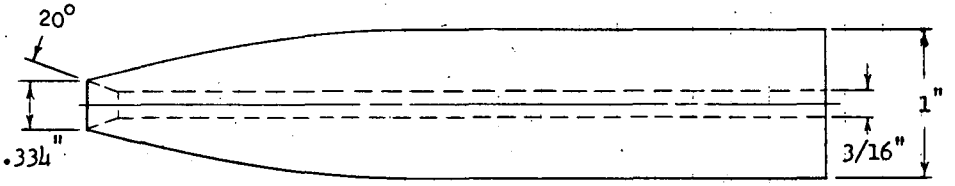


Figure 23.- Variation of total-pressure error with angle of attack.
M = 1.62. Tube D-5.



Tube E-5

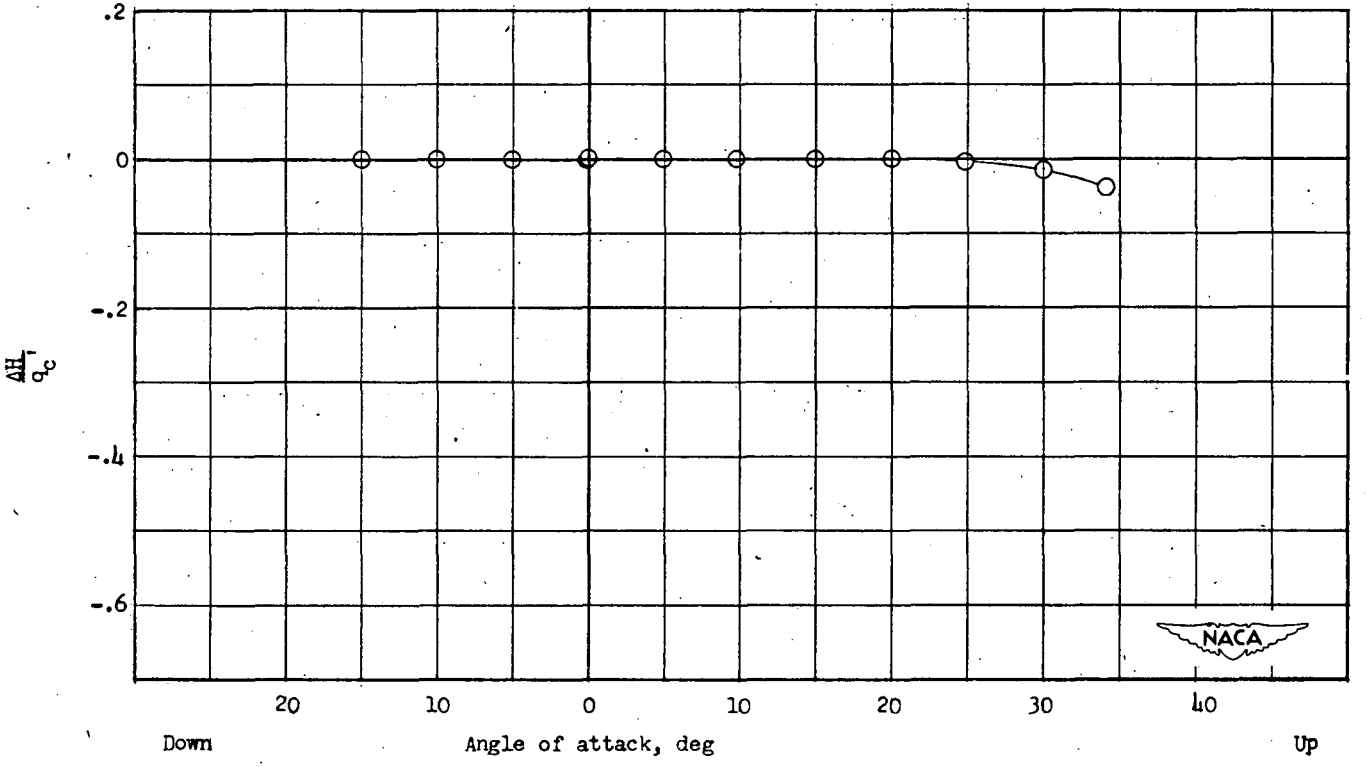


Figure 24.- Variation of total-pressure error with angle of attack. M = 1.62. Tube E-5.